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MODERN TECHNIQUES
OF EXCAVATION

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PREFACE

MODERN TECHNIQUES OF EXCAVATION is the third book of a practical, generously illustrated series on earth-moving. It provides complete information about the planning and execution of excavation and grading projects of all kinds, but does not include details of the construction and basic operation of equipment.

The text follows closely the section of MOVING THE EARTH titled "The Work," and describes each type of job the earthmover must do, the problems that arise, and the planning, supervisory, and operational techniques used in solving them.

Two chapters deal with financial management, estimating, insurance, and certain aspects of equipment maintenance that are important to the excavating contractor. New material includes a discussion of certain undesirable features of present day equipment.

A glossary containing definitions of more than 1200 terms used in the industry and a 32 page Appendix of technical information have been reproduced from the larger book. There is a complete new index.

MODERN TECHNIQUES OF EXCAVATION has been prepared to fill the special needs of the works planning and field men in contractor and engineer organizations, in a briefer and more easily handled volume than the all-inclusive MOVING THE EARTH from which most of its material is derived.

The enthusiastic reception of the earlier books, as evidenced both by substantial sales and high praise from reviewers in practically every publication in earthmoving and associated industries has given confidence in continuing a series of specialized books, each of which is directed toward the needs of particular groups.

The text and illustrations have been checked and rechecked for accuracy and completeness. The publisher will appreciate being notified of any errors or omissions that may still be found, and will be interested in descriptions of practical techniques that differ from those described.

Herbert L. Nichols, Jr.
GREENWICH, CONN.
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MODERN TECHNIQUES
OF EXCAVATION

CHAPTER ONE

LAND CLEARING

Areas which are to be excavated, filled, or graded often must be cleared first.

Clearing usually involves removal of vegetation, which may be grass and weeds, brush, trees, and stumps. Other material which may be taken away before actual dirt work starts includes boulders, walls, and buildings or their foundations.

HAND CLEARING

Hand cutting may be the most economical method of removing the aboveground part of small patches of brush, or clearing larger areas so swampy or rugged as to make use of machinery difficult. In addition, some handwork greatly facilitates most types of machine clearing.

The brush is usually burnt, although in narrow rights of way it may be piled at the sides. If conditions permit, it is best burnt immediately upon being cut to avoid rehandling. If smoke nuisance or fire hazard prohibits this method, it can be piled and burned after the cutting crews are out of range, or after it has dried out.

Cuttings may also be ground into chips, hauled away, or both, to avoid having fires on the job.

MACHINE CLEARING

Dozers. A dozer is the standard machine for clearing. It works best when the ground is firm enough to support it, and is without pot-holes, gulleys, sharp ridges, and rock. Uneven surfaces make it difficult to keep the blade in contact with the ground, and lead to burial rather than removal of vegetation in hollows. However, there are few places where a dozer cannot aid hand clearing crews, by clearing areas where it can work, moving logs and cut brush, cutting roads for supply trucks, or firebreaks.

Dozers have a particular advantage over hand crews where briars and vines are abundant, as these are very tedious to cut but can be readily stripped off by the blade, provided the operator does not take too long a pass and get caught in the tangle.

Light dozers, of the two-ton class, can work on very soft ground if it is crusted or covered with sod.

Brush and small trees may be removed by a bulldozer walking with its blade in light contact with the ground. It will uproot or break off a number of the stems, and bend the rest over so that by a return trip in the opposite direction, it can take out a number more. If the distance is short, it is best to doze the whole patch in one direction, then across or backward.

Individual small trees are first knocked over then pushed out with another pass in the same direction.

Results will vary with the type of vegetation and the condition of the soil. Hard-baked soils will cause a high percentage of broken stems, while wet or sandy conditions favor uprooting, which is more satisfactory for most purposes. The work can be speeded by having a laborer cut out or

pick up individual bushes that would otherwise require another pass by the dozer.

If the job requires removal of light stumps and roots, they may be overturned in one pass and pushed out in the next. It may be necessary to dig several inches into the soil to get a grip on them, then backblade the soil into the holes.

Brush heaps may be largely freed of dry loose dirt by rolling them over with the blade and shaking the blade up and down. If this is ineffective, rolling them over backward or pushing them from the side may be tried. A dozer with a blade which can be easily tilted down on either end is very good at this work, as one corner can be used for taking out roots, and pushing piles without taking a bladeful of dirt along with it, and the blade returned to flat position to skim off surface brush.

Rake Blades. The best tool for grubbing is a special dozer blade having teeth projecting downward from a solid edge. These brush rakes enable the teeth to work below ground level, taking out roots as well as surface material, while most of the soil may sift back to the ground through the spaces between the teeth. These machines will remove small or loosened stumps and loose rock in the same operation.

A shoveldozer with a hydraulic dump bucket fitted with teeth does the same job, except that the teeth are shorter and therefore do not penetrate as deeply or sift dirt as well. This machine can also pick piles up and carry them or put them on trucks; build very high piles; dump brush on top of fires; can compact brush over a sulky fire by patting with the bucket, and pep it up with the forward moving air current from its reversed radiator fan.

Any sort of mechanical removal of brush that is to be burned should be done when the soil is dry for best results. If it is dug in the wet, a lot of mud will stick to it. This can sometimes be shaken out again when dry by rolling and pushing the piles.

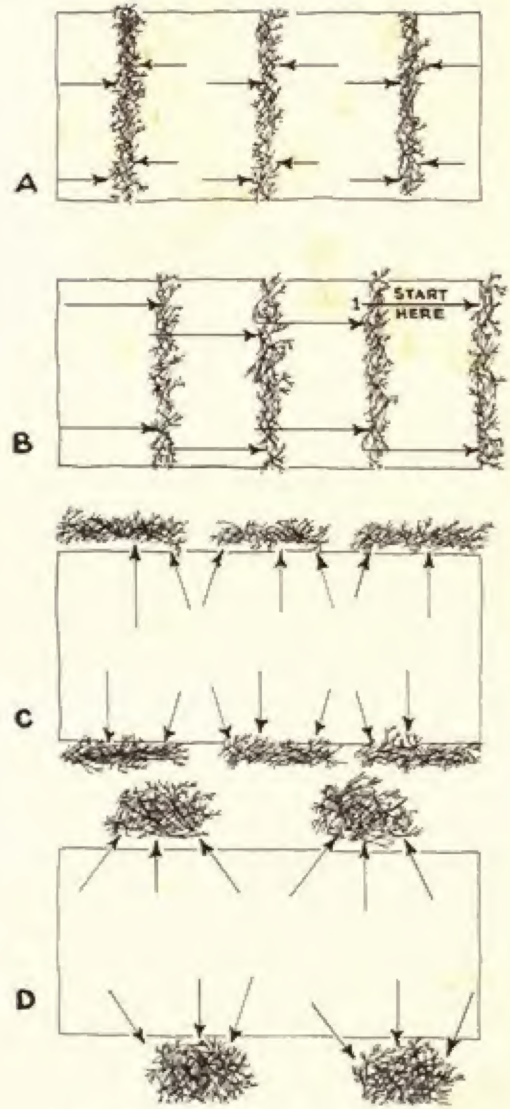


Fig. 1-1. Piling brush with dozer

Work Patterns. In agricultural clearing, vegetation is frequently pushed into straight windrows, where it is burned after drying, or is allowed to decay. The width of cleared aisles will depend on dozer power and the heaviness of the growth. Single pushes may range from fifty to over two hundred feet.

The simplest method of windrowing, Figure 1-1 (A), is to push from two directions toward a center line. This has the disadvantage of burying some vegetation without loosening it, which will increase

difficulties in burning or moving the pile, and require further clearing after burning.

The pattern in (B) avoids this difficulty by building the windrows on cleared land. However, any windrow or large pile of brush, particularly if it includes trees, may be very difficult to rehandle. Brush, roots, trees, stumps, and dirt are crushed into a mat which often cannot be moved again by the dozer that built it. Except in highly inflammable growths, such as fat pine and palmetto, the mat may be difficult or impossible to burn, even after long drying.

If it becomes necessary to remove a tangled heap, a larger dozer, or a clamshell, dragline, or hoe shovel may have to be used. Taking it apart by hand might be more costly than the original clearing.

When piling coarse brush or trees, it is often advisable to have them cut into lengths of ten to twenty feet, after uprooting. This will enable the dozer to handle larger loads and to place them more accurately. Piles can be more readily separated or moved if necessary.

When a right of way is cleared, and immediate burning is not required, the brush may be stacked in windrows, as in (C) or in piles as in (D), outside of the work area.

Burning. In general, however, it is the best practice to burn machine cleared vegetation at the same time that it is piled. A hot fire, including heavy wood, is prepared and brush piles pushed up on it. A new fire is made when the push gets too long.

Best results are obtained if the vegetation is uprooted and allowed to dry at least a few days before burning. This may be done by backing the dozer into the woods from the cleared edge, and uprooting small patches, or individual trees, pushing them clear of the ground, and then leaving them.

The trash dries more rapidly scattered on the ground than in piles. Dirt will tend to dry and break away from stumps, and to sift out of roots and stems.

When burning, the brush nearest the fire is put on it first.

Fires fed by a dozer tend to get choked up with dirt. In general, matted light brush is more difficult to clear and to burn than heavy brush or small trees, as it tends to slip under the blade, or to bring too much dirt with it.

The ideal combination for heavy clearing and burning is a large dozer and a clamshell shovel. The dozer can uproot and push in brush and trees, and the clamshell can pick them up, shake the dirt out, and pile them on top of a fire. The clamshell can also move unburned ends in and maintain the fire.

A clamshell is also the best tool for use in piling brush for future fires, and for burning old piles or windrows which require rehandling.

Dozer Protection. When a dozer is clearing dense undergrowth, there is the danger that it will fall into some hole, natural or artificial, whose presence is concealed by the brush. This may be guarded against by scouting the area on foot, and by moving forward in a succession of short pushes overlapping each other on the side, as in Figure 1-2. This enables the operator to watch from one side, without getting branches in his face, and to observe the nature of the ground. In addition, it avoids tangling the dozer in branches and vines.

Any dozer used for clearing work should be thoroughly protected with crankcase and radiator guards; the latter including screen with holes not over one quarter of an inch, and accessible for removal of leaves and trash. Care should be taken not to let branches jab into the fan or radiator while backing up, or to allow them to tangle with hydraulic hoses or other vulnerable parts at any time. The operator should carry hand pruners and an ax or machete to cut himself out of tangles.

Accidents have been caused by branches moving throttle and clutch controls.

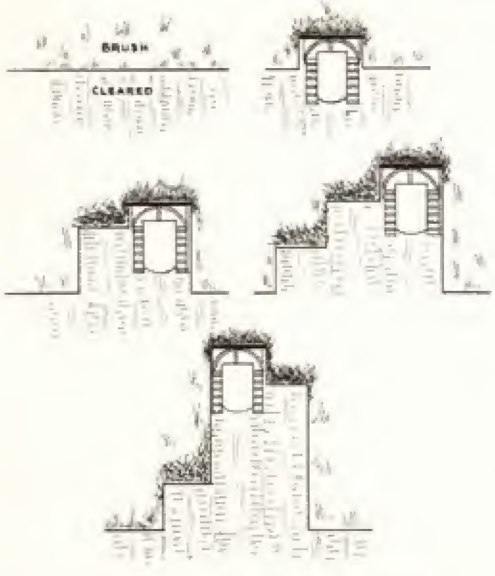


Fig. 1-2. Clearing thick brush

Cable Drag. Two powerful dozers or tractors may start land clearing by moving through the growth on parallel paths, dragging a heavy cable between them. This cable should be strong enough to take the pull of both tractors, and long enough not to pull trees on top of them. On the first pass, the cable will pull over most of the vegetation, uprooting or breaking off some. A return trip is made on the same path, uprooting most of the remainder under favorable conditions. The loosened material is then piled by clamshells, or by dozers, preferably with rake blades.

A third dozer may follow closely to help with any tree which the cable cannot handle, and push out overturned stumps.

This method is not effective against low stumps, which can be avoided by supporting the cable on a hollow steel ball.

Disc Harrows. Weeds, soft sod, and light to medium brush may be chopped up by a heavy disc harrow. The discs should be notched and be 24 inches in diameter or larger. It should be weighted down and towed by a tractor powerful enough to travel several miles an hour, as speed increases its effectiveness. It is dragged through the standing brush (after scouting on foot), and in soft ground may uproot and chop to pieces most of the growth. The loose pieces may be removed by hand or by a pushing or raking machine.

Several passes may be required. When the brush becomes loose enough so that it moves back and forth freely under the discs, the harrow will cease to be effective.

Plows. Sod and weeds may be turned under by a mold board or disc plow, then be chopped by a light disc harrow.

A single bottom plow, particularly of coulter-knife variety called brush-breaker plow, may put brush and even saplings underground when pulled through them by a heavy tractor. The field can then be disced lightly and seeded to some crop not requiring cultivation. In a season or two all of the original vegetation except occasional trunks will have rotted, and these may be removed by hand when plowed up. This is strictly an agricultural operation.

Sickle Bar. A heavy duty hay cutter will usually cut brush up to ¾″, and single stalks 1″ or more, although with some wear and breakage. If the area is cut over about once a month for a while afterward most of the growth will die, and any survivors can then be grubbed out.

Oversize plants should be cut flush with the ground before using the sickle bar.

Rotary Choppers. The Bushwacker disintegrator will tear up brush and trees up to six inch diameter, and leave the fine fragments as a ground mulch.

A rotary tiller of sufficient weight will chop brush, roots, and small saplings into fragments which may be mixed with the soil by leaving the rear door of the tiller down, or scattered on the surface for raking and burning by leaving the door open. Best results will be obtained by equipping the machine with special brush knives that will reduce the winding of branches and vines around the rotor.

Cleanup. When the final cleanup of any

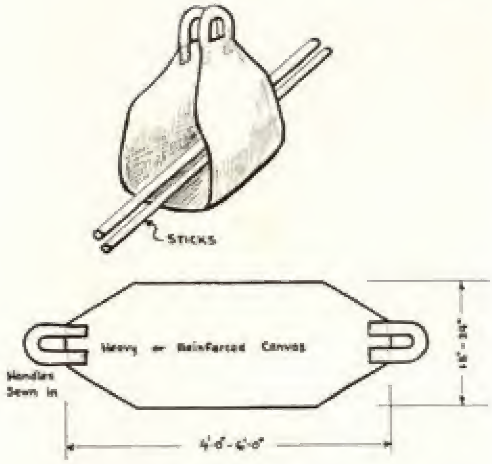


Fig. 1-3. Trash carrier

kind of brush clearing is done by hand, it is helpful to furnish laborers with stick carriers, which may consist of a piece of heavy canvas, six or more feet long, and two to three wide, with handles on the ends, as in Figure 1-3. This is laid on the ground, and sticks and branches piled across it. The handles may then be picked up and several armfuls carried at a time with minimum effort.

LOGGING

Subcontracts. If trees are to be removed which are of no value on the job, an attempt should be made to sell them. To the contractor desiring to confine himself to dirt work, the best arrangement is to get the customer, whether sawmill, firewood dealer, or whatever, to buy the trees on the stump and cut and remove them. A danger is that the logger may fail to do the work in the time specified, and so force the contractor to do it himself at the last moment. In making such an arrangement, the disposal of the scrap wood and brush and the height of the stumps should be specified.

A sawmill operator is interested only in large sound trunks, whereas a pulp or firewood man can use bulky branches also. The mill will ordinarily pay the best prices, but do the least work toward cleanup of the tract, unless it has an arrangement with pulp or firewood users to take its tops and limbs.

No one wants the rotten trees, crooked branches, and brush, but the lumbermen may agree to burn them, if this is a part of local logging practice; or if the contractor accepts a complete cleanup job as part or full payment for the wood.

Cooperative clearing arrangements may be made in which the logger is assisted by the contractor's tractors or trucks.

Stump Height. Stump height may be determined by local law or lumbering custom. From a clearing standpoint, high stumps are more easily removed than low ones, and are especially desirable when the machinery is undersize for the job, or depends primarily on winches. Low stumps are more difficult to cut, particularly where the trunk flares out widely at the bottom, but do not impede machines as much, and can often be filled over and left.

Cutting. If the trees are valuable and lumbermen will not clear them out in time, the contractor may cut and stack them for future sale. This, as a logging proposition, is somewhat out of the field of this book and will be considered very briefly.

The undergrowth should be first cleared out to reduce danger to personnel and tangles with fallen trees.

Small trees may be chopped or sawed, large ones sawed. The saws may be of

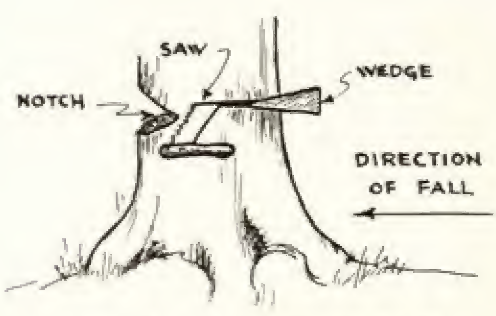


Fig. 1-4. Use of saw and wedge

the power chain type operated by one to three men crews, or two man hand crosscut. The tree should be notched on the side toward which it should fall, then cut through from the other side, as in Figure 1-4. Unless very much out of balance, it can be forced to fall in the desired direction by inserting wedges behind the saw, then driving them in with a sledgehammer. This will widen the cut, relieve possible binding against the saw, and tip the tree in the right direction.

When the tree starts to fall, its full weight is carried by a narrow strip at the back of the notch, and the wood at that point may be crushed. If the saw is caught there, a handsaw may lose its set, and a chain saw be so pinched as to need immediate repair. The saw should therefore be pulled back toward the wedge, or clear out of the cut if possible, as soon as the fall commences. Inexperienced workers will do well to cut with a chain saw to the critical point, take the saw out, and complete the cut with a hand crosscut and wedges.

In any case, personnel should be alert to pull the saw back as the tree starts to lean; and to move rapidly if it falls in an unexpected direction, or if it breaks off overhead. It is at this time that brush or litter underfoot may have fatal consequences.

A chain saw that is not being used, or the generator for an electric saw, should be put behind another tree or other protection.

Leaners. A tree may fall against other trees and be held from reaching the ground. If machinery is available, the butt may be chained and pulled until the top falls. A small or medium tree may be moved by putting a log or other fulcrum beside it, prying it up with a pole, sliding it a short distance, repeating this as many times as necessary.

If the trunk will not move, it must be cut in the air. Because of the strain this position places on the trunk, cuts from the top will be difficult to keep open even with wedges, and these are often difficult to drive. The trunk may be notched on the top with ax or saw, then cut from below. Logs bucked in this manner are liable to split.

Trimming. When the tree is down, the branches should be cut off nearly flush with the trunk, before any other trees are dropped across it to make a tangle. Light branches and any heavier wood which is to be wasted, should be piled, burned, chopped up, or taken away by methods described for brush.

Removal. The trunks may be dragged out of the woods by tractors, or cut (bucked) into lengths where they fall. Saw logs for small mills may be from eight to sixteen feet long, the size being largely determined by the use for the sawed wood, the capacity of the mill, and of the trucks that carry the logs. Piling, which may often be made from thinner trunks than saw logs, is left full length. Cordwood is usually in four foot sections, and split to a size that one man can handle. Pulpwood varies in length in different localities and is usually peeled but not split.

Dragging Logs. Crawler tractors are the standard tool for dragging long logs. Their efficiency may be increased by mounting winches and dozers, and by use of log carriers and various rigs too specialized for description here.

A log is usually pulled by means of a chain or cable fastened around its butt, choker fashion, and attached to the tractor drawbar or winch. The most important consideration in arranging this is to get the butt off the ground, or riding on it very lightly, as digging in will take greatly increased power and will rip up the trail. A short line, particularly to the top of a winch, is helpful unless the log has a greater diameter than the height of the drawpoint.

The log may also be pulled onto a

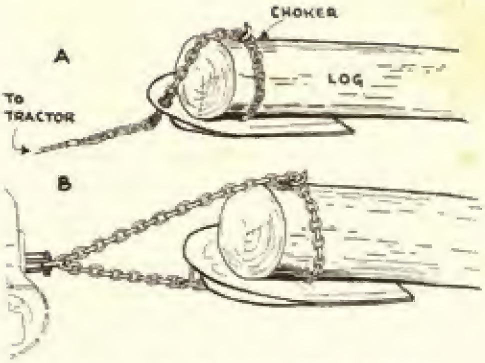


Fig. 1-5. Skid-pan log hitches

stoneboat, or other sled, and the line passed through the eye, or two lines used as in Figure 1-5.

If the tractor is sufficiently powerful, several logs may be pulled at a time by attaching them individually to different lines. If only one line is available, they may be fastened with one choker, as in Figure 1-6, which should be fastened well back, as such piles often come apart while being towed.

Wheel tractors can drag logs through dry terrain, and although the loads will be smaller, they may move much faster. If the tractor has a hydraulic lift drawbar which can be chained to the log to lift its butt off the ground, its efficiency is more than doubled, as the weight on the driving wheels is increased, and friction greatly reduced.

Bucking. If the trunk lies on uneven ground, or is partly supported by the stump and branches, it will settle as it is cut from the upper side, closing the slot and pinching the saw. This may be prevented by raising the trunk at or near the cut by means of auto or house jacks; or, for small trees, by raising with a pole used as a crowbar, and blocking it up. Another method is to drive a wedge or wedges behind the saw to hold the cut open. Or, before the tree is cut, a log may be placed so that the trunk will rest on it where it is to be bucked.

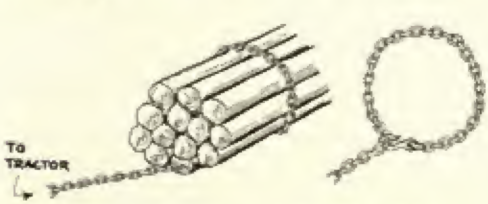


Fig. 1-6. Fastening poles for towing

Proper bucking may be prevented by obstacles such as stumps, brush, rocks, or dirt. Sometimes the obstacle can be moved, sometimes the trunk can be slid, rolled, or lifted free, or cuts may be made at other places until the trunk can be moved. The most frequent trouble is the tree partially burying itself in soft earth, so that cuts cannot be carried all the way through. This may be prevented by dropping the tree on logs placed to support it, or overcome by trenching the dirt for the saw, or jacking up the trunk.

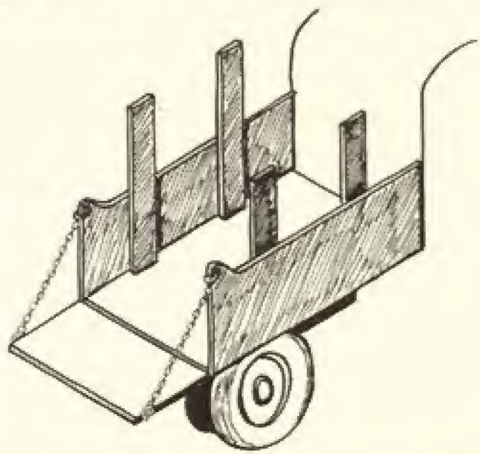


Fig. 1-7. Sideboards to hold cordwood

Moving Short Wood. When trucks can get in the woods, cordwood and pulpwood are usually cut to size and trucked out. As wood is much lighter than dirt, a dump truck can carry several times its body capacity, if the pile will stay on. Figure 1-7 shows a method of placing planks, poles, or thin split logs vertically along the body sides to permit high piling. These are held in place by the piled logs. If the road is

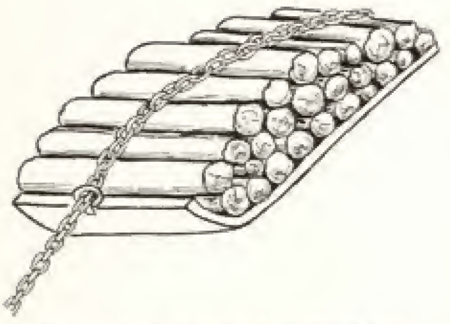


Fig. 1-8. Cordwood on stoneboat

rough, it is wise to pass a chain from the body over each row of logs and to tighten it with a load binder.

If the wood is cut short, and rain or unforeseen mud conditions make trucking impractical, it may be dragged out by tractors. If a stoneboat is available, logs may be piled on it, and the tractor line threaded through the eyehole over the pile and anchored on the back. The eyehole should be beveled so that a chain or cable can slide freely through it, as the tractor pull will then hold the logs to the stoneboat. See Figure 1-8. If no boat is available, the logs may be piled on the line which is then looped around it as a choker. Parts of the piles may be chained by snaking the line under them, without repiling.

Storage. Wood should be stored outside of the work area where it will be accessible both during and after the digging. Poles and logs may be very useful in shoring up banks, making corduroy roads, getting machinery out of the mud, and other purposes. A buyer might be found for the wood at any time. Stored logs or cordwood should be stacked so as to be off the ground and well ventilated. This makes it easier to remove them later and delays damage from rot and borers. Cordwood is usually stacked in easily measured units.

Personnel. If possible, experienced loggers should be employed for lumbering. They will be able to do it much more efficiently than equally energetic and resourceful men not used to the work.

STUMP BLASTING

The most serious problem in tree clearing is the stumps. A few species are valuable enough in certain localities so that they can be sold for more than the cost of digging, but the vast majority of them are worthless and present a difficult disposal problem.

Dynamite may be used to blow stumps clear of the ground, to loosen or lighten them, or to break them into pieces. Stumps respond best to slow acting dynamites, but the standard 40 percent grade will usually give satisfactory results.

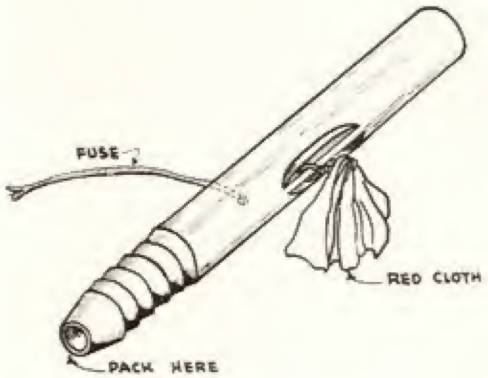
Underground Charges. A hole, or several holes can be made under the stump by punching with a crowbar, or paving breaker, or drilling with an auger. Easiest penetration is usually obtained close to the trunk, between heavy root buttresses. Several tries may be necessary. If no hole can be made deep enough exploding about a tenth of a stick of dynamite in a shallow one may soften up the resistance.

A heavy enough charge should be placed to blow a crater in the ground large enough to include the stump and its major roots. A pound of dynamite should move about a yard of dirt, but the charges should be varied according to results obtained.

If the stump has a taproot, a substantial part of the charge should be in direct contact with it in order to shatter it.

If one charge is placed, it may be exploded by either fuse or electric caps. If more than one, electricity should be used so that they will go off together. If the charge is too small, it may merely create an underground chamber; if too large, it may carry the stump or its fragments into forbidden territory. The desired result is to split it, and lift it clear out of the ground, without excessive after-travel.

Wood Drilling. A stump may also be blasted apart with a smaller charge by drilling directly into the wood. A one and one quarter inch drill will make a hole



Courtesy of The Thunderbolt Company

Fig. 1-9. Thunderbolt splitter

large enough for standard dynamite sticks. If smaller drills are used, the dynamite may be obtained in thinner sticks, or unwrapped and stuffed into the holes. Hand extension bit drills are generally used, but if a quantity of stumps are to be blasted this way, an electric drill powered by a portable generator will be a big time saver.

A stump blasted in this manner is usually shattered but not blown out of the ground. The pieces are generally easier to pull or dig out than the whole stump, but not always.

Mudcapping. If it is impossible to get under the stump and no drill is available, it may be broken by placing charges between the root buttresses and packing mud over them. The mud turns the force of the explosion inward and lessens the noise and concussion. The mud must be free of stones and pebbles as they fly like bullets. A stump blasted in this manner is easier to dig out than when whole, but may be more difficult to pull.

This type of stump may also be loosened by cutting the main roots with blasts several feet out from the trunk. The dynamite is removed from its wrapping, packed closely against or around the root, and covered with mud or damp earth.

If the first blast does not loosen the stump sufficiently, another can be placed. In circumstances where the charges cannot be properly placed because of rock, lack of tools, or danger of damage to nearby property, a series of blasts may be needed. If the dirt has blown away from the roots, their effectiveness is greatly reduced and an ax may do better work than more powder. If the roots are entangled with bedrock or massive boulders, the rock may have to be drilled and blasted.

A standing tree may be blasted in the same manner as a stump, but a much heavier charge is required to lift it enough to break the roots. However, a moderate off-center blast may cause the tree to fall, in which case its own weight will snap a large number of roots. Trees felled by blasting are likely to be badly split and useless for lumber.

If a large stump must be removed by hand, or with small machinery, it may be necessary to break it up after getting it out of the ground. A Thunderbolt splitter, shown in Figure 1-9, is effective at splitting loose stumps and heavy logs. A charge of black powder is inserted in the hollow at the narrow end, and held in with wadding while the tool is driven into the stump. A fuse is inserted and lit, and the explosion usually tears the wood apart and throws the tool a considerable distance. Tying a large brightly colored rag to the splitter reduces its travel and simplifies finding it.

Precautions. Stump blasting is dangerous work at best because of unpredictable conditions underground. Particularly, a rock may be held just over the charge by roots in a position that will cause it to take off like a mortar shell. Split pieces of wood will also fly long distances. Mud or earth packs over charges should be free of stones or pebbles, and personnel should move a long way back from the blast, unless good shelter is available.

All stumps should be accounted for after a blast, as they are sometimes blown up

in trees, where they stay until dislodged by wind or another blast, with serious results to persons underneath.

If the blasting is to be done near buildings, logs or saplings chained together should be piled on the ground on the side of the stump toward the building, to stop stones and fragments from flying. Regular blasting mats are safer, but if machinery capable of handling them is on the job, it generally can pull the stumps without the necessity of using explosives in close quarters.

Applications. Blasting ahead of stump moving machines has several uses. It reduces the power requirement, which is good when the stump is big enough to argue with the machine, and saves time in any case. A factor which is often more important is that blasting the stump loosens the mass of earth held by the roots, so that much or all of it will fall off during handling. This earth is a large part of the weight of many stumps and increases the difficulty of moving and burning them. Blasting is ineffective at removing the dirt once the stump is out of the ground.

Stump blasting is generally ineffective in sandy or powdery soils, as the force of the explosion flows around the roots with minimum breaking effect. These soils also fall off the stump rather readily without blasting.

The relative size of holes left by blasting and by pulling varies with tree species and soil conditions.

PULLING STUMPS

A standard method of taking out stumps is to pull them by means of a line around the trunk. The line may be a chain, cable, or rope, and the power may be direct pull by a machine or animal, winding in of cable on a winch, either machine or hand powered, or a combination of these methods with pulley blocks.

The stump line is generally a choker type which tightens its grip as the pull increases. In smaller sizes, chain is preferred because it is easier to carry, safer to handle, and more resistant to abuse. However, it is much heavier than cable for the same strength, and in large sizes is too weighty to be practical.

Line pulling is preferred when the ground is too rough or soft to allow machinery to get at stumps directly, and when available force needs to be increased by multiple lines.

Chains. A more detailed description of chain and fittings will be found in Chapter 21. A standard tow or logging chain is composed of short straight links, carries a round hook on one end and a grabhook on the other. The round hook may be fastened to the chain by a ring, or a ring may be used instead of this hook.

Either the round hook or the ring can be used in chokers. The hook is easier to attach and to detach, but may fall away from the chain when it is slack. The ring may be used by passing the grabhook through it and pulling from the grabhook end; or for stumping, the chain near the ring may be pulled through it to form a loop that is dropped over the stump.

The grabhook fits over any individual chain link, and will not slide along the chain. It is used to adjust the length of chain by increasing or decreasing the amount of double line, by moving it toward or away from the choker end, or passing the chain behind a tractor drawbar pin, and preventing it from being pulled out again by attaching the grabhook to the slack side, making it too large to be pulled through the space. In this case the surplus chain is slacked, and if it is long, must be hung on some part of the tractor. See Figure 1-10.

Grabhooks are used to anchor a chain to a tree that is to be saved. The lack of sliding pressure makes it possible to protect the bark by pads and sticks placed

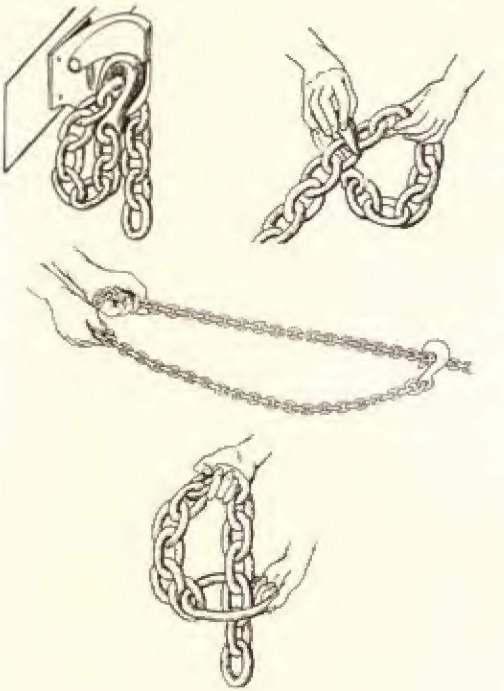


Fig. 1-10. Grab hook uses, and stump choker

on the side receiving the pull. The grab-hook may also be used to make a ring which can be used to make up a choker.

Figure 1-11 shows three ways of fastening a chain to a stump. In each case, the stump is shown to be grooved by an ax at the back. This cut is quickly made and will prevent the chain from squeezing off during the pull, and will delay its slipping off as the stump leans. (A) is the easiest and most usual method, pulling at the center; (B) is a side pull, a little harder to arrange, but which puts less of a kink in the line, so that it can be used with cable as well as chain, and gives the advantage of a twist on the stump; and (C) the overhead method which requires an inverted T notch. This gives the greatest leverage but is more likely to slip off than the others.

Care should be exercised not to put loads on a chain that is twisted or kinked as it will be broken or damaged. It can be readily checked for straightness as the links which are in one plane should lie in a straight line.

Alloy steel chains weigh only about a third as much as standard chains in proportion to strength. If a crew is careful enough not to lose chains, and is conscientious enough not to abuse them by kinking or gross overloading, alloy chains will amply repay their much higher cost in reduced

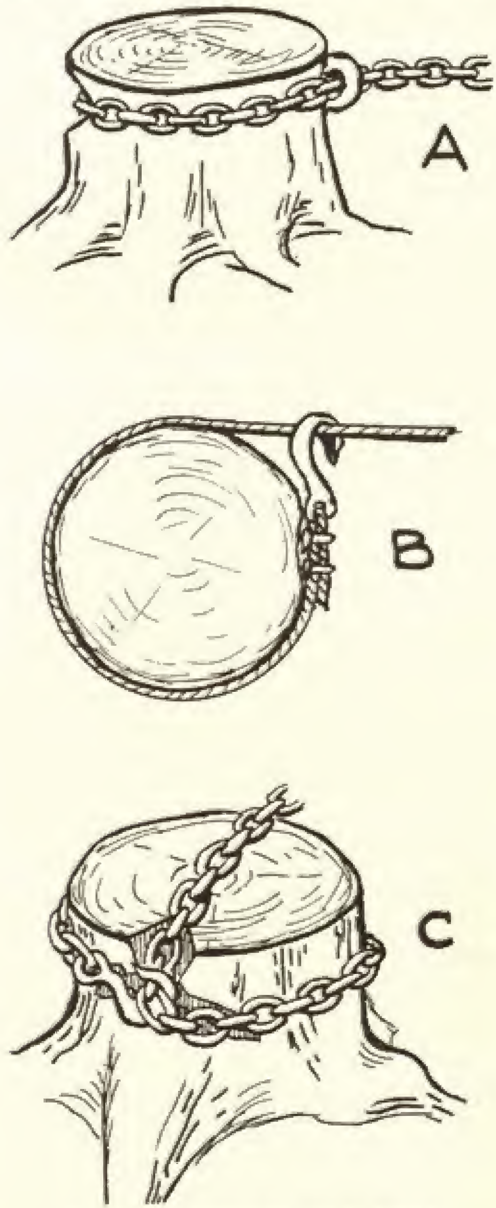


Fig. 1-11. Fastening line to stump

labor and fatigue, and by greater efficiency.

As an example, one ⅜" alloy chain, weighing 1.6 pounds per foot, is thirty percent stronger than the same make of ⅝" ordinary chain, weighing 4.1 pounds per foot.

It is recommended that the alloy chain be dipped in bright red paint so that it can be easily recognized, and recovered readily if mislaid.

Broken Chains. A broken chain is best repaired by having new links forged into it by a blacksmith. However, good field repairs may be made with a variety of patent repair links, or by shackles with removable pins. Links that have been stretched thin may not admit the proper size repair piece, and may have to be cut off with a chisel or hacksaw, or opened by supporting on a block with a hole in it, and spreading with a punch and hammer.

A broken chain may be used temporarily by making a square knot and tying the end links together with wire or string. If there is not enough chain, a half knot should be used and the ends fastened with a bolt. A bolt may be used without any knot, but will pull apart more easily than a link. Two grabhooks connected by a ring can be used for temporary repair and for shortening.

If the chain is too weak for the job, an attempt should be made to double it. It may be looped around the load and fastened by its two end hooks or rings to the drawbar. If it is looped around the drawpin, links may be bent or crushed.

Cables. Only the method shown in Figure 1-11 (B) should be used in pulling a stump with a cable choker, as the sharp bends involved in the others will cause early breakage of the cable.

If a double cable line is used to reduce strain, or to shorten the rope, it should not be bent around sharp angles. A stump is generally round and smooth enough not to cut a cable wrapped around it, and the end hooks or loops can be attached to the drawbar. If the load is angular, it is better to fasten a snatch block to it with a chain or sling choker, and to run the long cable through the block pulley.

If a double cable is so wrapped around the load that it cannot slide around it, great care must be taken to adjust it so that both ends share the strain equally, unless a single line is strong enough to take the entire pull alone.

Root Hook. A root hook may be used when a stump is too big to pull directly Enough soil is dug away to expose the lateral roots, the hook is placed to grip one of these, power is applied, and the root torn out. This process is repeated until the stump is sufficiently weakened to be taken out on one of the root pulls, or by direct pull on the butt.

The root hook may also be laid on top of a stump, with the teeth in a notch on the back. A pull on this gives excellent leverage, but the edge of the stump is liable to tear off.

Taproots. The presence of a taproot increases resistance of the stump. If the ground is hard, this root may be broken or pulled apart. If the ground is soft, or the wood very tough or pliable, the pivot point may crush and the root bend so that the pulling power is exerted directly against the length of the root, without benefit of leverage. In such a case, the upper roots of the stump may be torn up sufficiently so that an ax, or a special long chisel, can reach and cut the taproot. The cut should be made while pulling as tension makes the wood part more easily.

Pulling Clear. If the force is sufficient to uproot a stump, the roots opposite the pull break first, then those at the side, permitting the stump to be pulled onto its side, as in Figure 1-12 (A). If the line does not slip off, the stump may be rolled and dragged out of the ground, but this often takes much more power than overturning the stump, and may be beyond the capacity

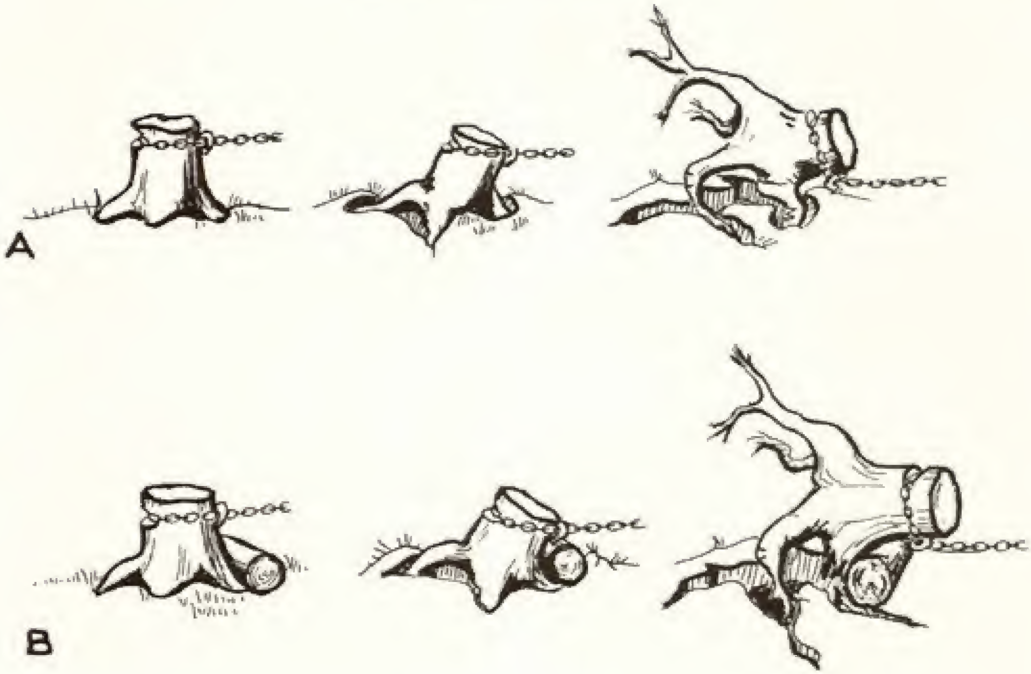


Fig. 1-12. Stump pulling

of the machine that is doing the pulling.

If the stump will not come all the way, the line may be slacked and a log placed or chained against the stump, as in (B). This log will provide a new fulcrum and aid the breaking out. Or the line may be taken off and the tractor moved to pull in the opposite direction, which should free it without difficulty. If a number of stumps are being pulled, all of them may be overturned one way, before pulling the tough ones in the opposite direction.

Half uprooted stumps are easily knocked out by dozers, and may be left for them to save the trouble of re-rigging.

Resistance. A stump's resistance varies in different directions. If on a slope, downhill pull is most effective. Otherwise it should be pulled toward its strongest roots, as these are easier to bend than to pull apart, and can be dealt with more easily when the rest of the stump is loosened.

The most obvious variable in stump resistance is its height. Greater height means greater leverage and easier pulling. Limiting factors are difficulty of high cutting, of fastening heavy chains at a height, and of the trunk breaking under pull.

A buried stump is the hardest of all to pull and usually must be dug out. On filled land, two separate systems of lateral roots may be found, one under the old ground level and the other near the surface, in which case it may be necessary to cut the trunk below the upper roots, in the same way as a taproot.

A stump which yields to pull but will not break loose, can often be uprooted by moving it as far as possible, slacking off to allow it to settle back, and pulling again, repeating this process a number of times. This is most effective if done slowly and smoothly, whether with winch or traction. This method is very effective with trees, as the trunk will bend with a whipping motion that exaggerates the force of both the pull and the snap back.

Chopping the roots on the side opposite

the pull, while they are under maximum tension, weakens the resistance. A moderate amount of digging will generally expose the main lateral roots.

When a stump has been split by blasting, the pieces are most easily pulled away from the center, rather than across it.

Uprooting Trees. If trees are so large that their stumps will be difficult to remove, it may be advisable to pull the trees over rather than to cut them down. This gives the opportunity to fasten lines as high as desired and to make use of the weight of the tree. As soon as the tree is pulled toward the tractor, its center of gravity shifts to that side and aids greatly at breaking out the roots. If a large log is chained to its base, on the pull side, the force of the tree's fall will be more effective at breaking roots on that side. The log will also serve to prevent the trunk from digging into the ground where it would be difficult to cut.

If the tree tends to break or split instead of uprooting, additional chokers may be used below the main pull point to distribute the strain and bind the trunk together. This can be done by pulling with two or more machines, or with multiple lines and blocks that will be described later.

If the trunk is smooth, a ladder will be needed to get a high grip. The chain may be held from sliding down by a nail, when necessary.

Pulling trees is apt to be wasteful of lumber as the bottom of the trunk may be put under such strain that it will split when cut.

Pulling Small Growth. Brush and small trees often grow where they cannot be reached by pusher machinery, because of soft or rough ground, or nearness to buildings. A landowner may wish to do his own clearing without hiring a dozer. Hand cutting may not be satisfactory because of sprouting. In such cases pulling techniques will be applied to small growth.

An automobile has sufficient power for pulling some brush and small, stiff-trunked trees, but the work doesn't do it any good. Trucks and farm tractors usually put more power on the job and are less likely to be damaged by the exertion.

If the stems are stiff, fastening may be made high for leverage. If they are flexible, height does not matter, and the greater strength of the base may make it the best place.

Chains tend to slide along smooth stems and they often can be made to grip by wrapping once or twice around before fastening. Light chain with small links holds much better than coarser types. A round hook or ring should be used to make a choker. If stems are close together, it is often possible to pull several at a time by putting a single choker around the group. It will slide up until it can pull them all tight together and then should hold.

Brush tongs get a good grip on small trees and flexible plants, and are easy to attach and to remove, but their weight may outweigh these advantages.

Plants too well rooted to respond to the power available may be weakened by digging out and cutting roots, or pulleys may be used to step up the power.

WINCHES

Power to pull stumps may be supplied by almost any machine or by animals. The crawler tractor is preferred for heavy work, but wheel tractors, trucks, and oxen may also be used. However, the most powerful, most convenient and best controlled pull is obtained from winches. These are most efficient mounted on crawler tractors, but may be on wheel tractors or trucks, or be portable units operated by a hand crank.

For general clearing work, the most effective tool is a bulldozer carrying a power winch. The winch consists of a heavy spool drum that is mounted on the back of the tractor and driven by the power takeoff. It is controlled by the tractor main clutch and

the power takeoff engagement lever. In addition, it may have a transmission, giving rotation of the drum in either direction, and in large machines permitting several speeds of rotation. A jaw clutch or neutral gear is used to disconnect the drum from the drive shaft, to allow it to turn freely when the cable is being removed. A brake is provided to slow or lock the drum when necessary.

The winch may hold two hundred or more feet of cable of a size proportionate to its power. Additional cable can be carried on a separate spool and connected to the winch cable by a choker device when needed.

In small sizes, the winch cable generally is fastened at the working end to a short piece of chain equipped with a round hook. Larger cables may be fastened directly, or through a swivel or single link, to a round hook, or a wide face cable grip hook. The cable is generally underwound on the drum, that is, leads from the work to the lower part of the drum. This gives better stability under heavy load than overwinding.

Stump Pulling. To winch out a stump, the tractor should be placed facing directly away from it, and both brakes locked on. The winch jaw clutch should be released and the brake set to drag very slightly, and the cable pulled to the stump by hand. If the brake is not used, the drum may continue to spin after being pulled, and unwind and snarl the cable.

If the winch will not freewheel, or the cable is very heavy, the drum is turned backwards by the engine to pay it out. It is convenient to have two men, one to operate the winch and the other to pull the cable. If no helper is available, the operator can stand near the winch while it turns, stripping the cable and coiling it on the ground until he thinks he has enough. He then stops the winch and drags the cable to the stump. The cable must then be whipped up and down and twists worked out to avoid kinking when pulled.

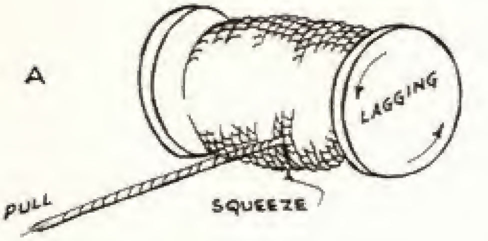
The winch cable may be put around the stump directly, hooked to a choker chain or cable, or may be run through one or more snatch blocks.

Power is applied to the winch and the cable is reeled in, care being taken to see that it feeds onto the drum properly. The stump may come out or the tractor may be dragged backward. If the latter, the tractor may be anchored by a chain from the blade or front pull hook to a tree. Resistance to pull may also be increased by backing it against a log or bank, or by trying to pull the stump by tractor pull and allowing the tracks to spin until they have built mounds behind them. If the anchoring or blocking is effective, the stump will come out if nothing breaks or slips and the engine does not stall.

The drum carries a number of layers of cable so that it has a greater spool diameter full than empty. It therefore reels in cable more slowly and powerfully on a bare drum than on a full one. On a bare drum, logging winches will give 50 to 100 percent more pull than the tractor itself; on a full drum, the same pull as the tractor or somewhat less. Special heavy duty winches may be obtained with much more power.

Jammed Cables. Using a nearly bare drum not only gives the greatest pull but reduces damage to the cable. If a long cable is wound smoothly onto a drum under moderate tension, and a heavy pull applied when it has built up several layers, the last wrap may squeeze between the wraps below, as in Figure 1-13 (A). This scrapes and wears the cable and jams it so that it will not spool off again. The best way to free it is to turn the drum until the catch is in the position shown in (B), and jerking it, or anchoring the end and driving the tractor away. Or, in the same position on the drum, the cable may be given a couple of wraps around the drawbar, and the winch turned backward as in (C).

A



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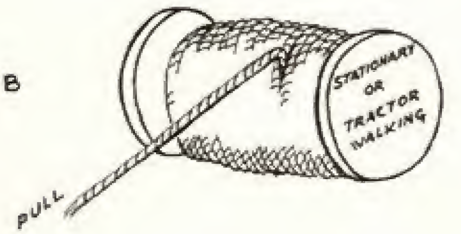

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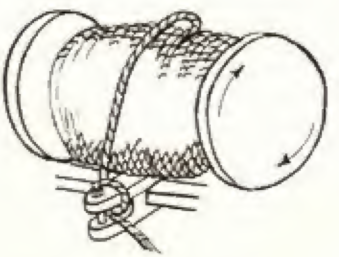


Fig. 1-13. Freeing winch cable

If the cable is wound unevenly onto the drum, with the wraps crossing each other at random, it cannot cut down between lower layers readily, but may put severe kinks in sections of cable that cross under it, and this cross wrapping may not entirely prevent it from squeezing in and sticking.

In spite of these difficulties, a long cable is desirable for general work. If reasonable effort is made to spool it in evenly while working, it will usually be rough enough to prevent excessive sticking, without too much bending or crushing.

Two-Part Line. Where the distance to the stump is less than half the cable length, a two-part line may be used by attaching a pulley to the stump and by running the line from the winch around the pulley and back to the drawbar. The useful strength of the cable and the pull between the tractor and the stump are doubled.

The tractor may have to be backed against a heavy log or an outside anchor used in the manner to be described below. The tractor should not be anchored by the front pull hook while using a double line anchored on the drawbar, unless the manufacturer will state that it is strong enough to take the strain.

Rocking. The winch and tractor pulls differ in quality and it may happen that the pull of the tracks will do jobs that the winch will not. Use of the tractor drive helps in "rocking" stumps or trees out. The line is left slightly slack and the tractor moved forward in low. As the line tightens, the stump may lean a few inches, then stop. When the tracks start to spin and the clutch is released, the weight of the stump, combined with the spring in the roots and in the line will pull the tractor back. The clutch is immediately re-engaged and held until the tracks spin or the engine lugs down again.

If the stump is within the tractor's power range, repeating this maneuver should gradually break it out. A long cable has more elasticity than a short one, or a chain, and will be more effective at rocking.

This procedure should not be allowed to degenerate into yanking, where the tractor is given a long enough slack run to be brought up with a jerk when it tightens. This will break more tractors and cables than it will pull stumps.

Cable Breakage. Cable or chain breakage is a serious danger to both operator and helpers. A cable particularly stretches under strain, and if it breaks suddenly, may whip with great force. The danger to the operator is greatest if the break is fairly near him. The cable used should be the

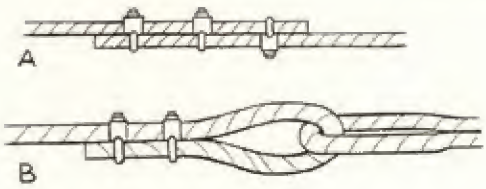


Fig. 1-14. Temporary cable repair

best quality, in the largest size recommended by the winch manufacturer, if the tractor is to be anchored or used for rocking; and it should be inspected frequently for weak spots.

Another danger inherent in the use of cable is cutting and tearing of the hands and clothing on broken wires. Preformed cable gives minimum trouble of this kind and should be used when possible. Leather palmed gloves are good protection for the hands.

Either hemp center or wire center cable may be used, according to preference or manuafcturer's recommendation. Wire center is about 10 per cent stronger, size for size, is stiffer, and is not as easily deformed by crushing. It is more difficult to handle, and when kinked or crushed is much harder to straighten. Standard 6 x 19 constructions are usually recommended.

It is good practice to work a winch at less than its maximum capacity, and to avoid anchoring the tractor unless absolutely necessary. Moderate loads give long life to cables and winch parts, and avoid severe catching on the drum. If the work is heavy, strain can be reduced by the use of pulleys and multiple lines.

Broken cables can be repaired by splicing, but the length of cable used in the splice, and the labor involved, may be too great to justify this method for the short cables ordinarily used in land clearing.

A rough repair may be made by trimming back the broken ends, overlapping them as in Figure 1-14, and fastening them with two or three cable clamps, for sizes up to half inch or five eighths, or with three or more for larger sizes. Or two interlocked loops may be made, as in (B), fastened with clamps, or any type of loop fastening. Cables repaired in this manner are weakened but may last a long time. The patch will not go through pulleys and is inconvenient in other ways.

Winches on Wheel Tractors. If a winch is mounted on a wheel tractor or truck, it is usually necessary to anchor it for heavy pulls. The anchor chain or cable should be attached to the winch frame, or to a heavy member as near to it as possible, to reduce strain on the tractor.

An important consideration in the use of these winches is the fact that the cable will tend to take a straight line between the work and the anchor. In making a high pull, as in Figure 1-15 (A), the tightening cable may lift the tractor and turn it over sideways. In (B) the downward pull may blow the tires, unless the axle housing is blocked up, as in (C).

If a wheel tractor is not anchored, a rear winch must be underwound, and care must be taken that the machine does not overturn through rising on the front, a danger which is particularly serious if the tractor is driven to move the load.

Winches that will pull loads up to fifty tons can be mounted on rather light wheel tractors.

Truck Winches. Truck winches may be of the spool drum type, and may be mounted in the front bumper, on a flat bed body, or between the body and the cab. Gypsy spool winches or catheads are generally mounted vertically on the forward part of a flat body.

The principal handicap of a truck winch is the difficulty of maneuvering it into position for a straight pull. One or more pulleys may be required to obtain a proper direction of pull and a straight line onto the winch. The truck should have all the wheels blocked, or be anchored by a line from a frame member near the winch.

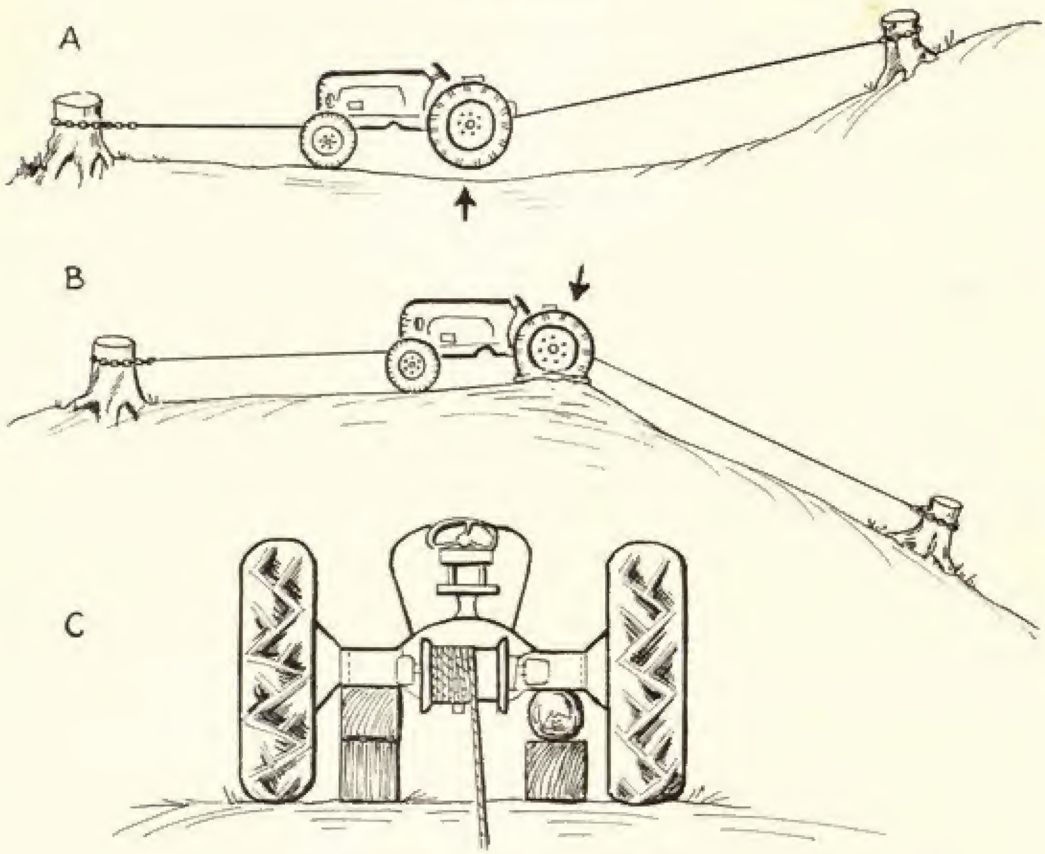


Fig. 1-15. Vertical effects of winch pull

The gypsy spool or capstan, Figure 1-16, does not carry cable. A hemp rope is looped around it two or three times, with one end attached to the work and the other end held by the operator. If the operator leaves it slack, the spool will turn inside the rope; if he pulls it tight, the working end of the rope will be pulled with great force. The slippage on the spool absorbs shocks that would break the rope and enables it to do very heavy pulling, under exact control. However, the gypsy is not ordinarily used for stumping.

Hand Winches. Hand winches are turned by a hand crank, operating through one or more sets of reduction gears. Under most conditions, it is not possible to make a full turn of the handle because it strikes obstructions, or passes through awkward positions. A large part of the work of winching consists in removing and replacing this handle, and if much work is to be done, a ratchet handle should be purchased, or made up by adapting one from a heavy socket set.

The winch is usually equipped with a friction brake and a pawl that can be en-

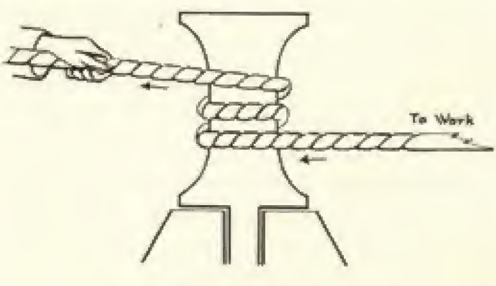


Fig. 1-16. Capstan winch

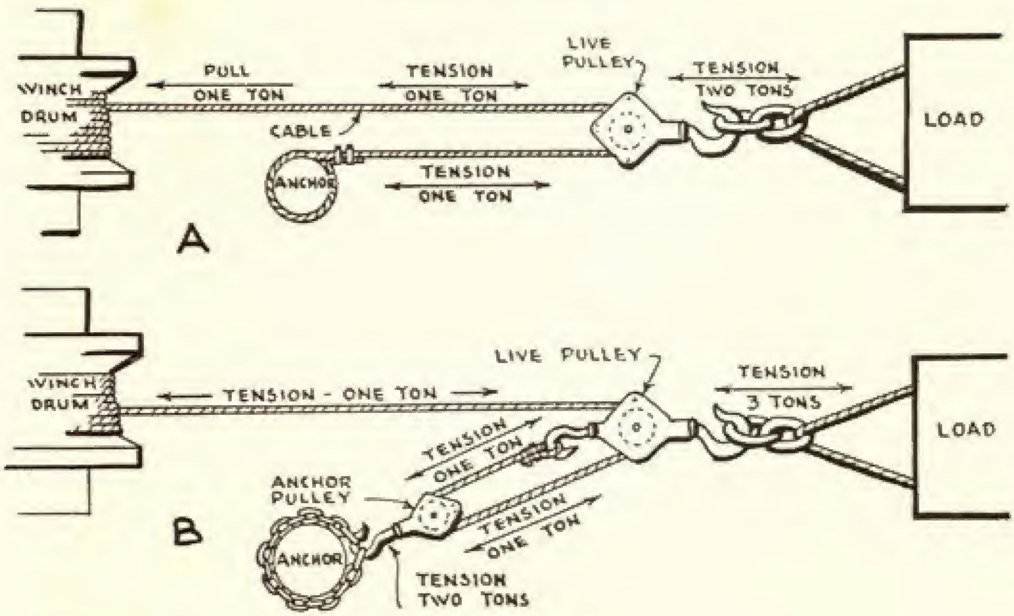


Fig. 1-17. Stump pulling layouts

gaged to prevent it from turning backward when the handle is released.

Operation of these devices is tedious because of the number of crank turns which must be made to reel in the cable; and exhausting because of the force which must be applied to the handle to develop the rated pull of the winch. It is important that it be thoroughly lubricated.

Hand winches can be used in places inaccessible to power equipment, are comparatively inexpensive and are surprisingly powerful. Sometimes they can take out tougher stumps than a power winch of the same pull because the line can be left taut and tightened gradually or from time to time as the stump yields. Their weight, with cable, may be from 75 to 300 pounds, so that carrying one of them any distance is at least a two-man job. Carrying or dragging it with a small tractor is often advisable.

Hand winches are sometimes mounted on a truck, in which case they serve largely as a spool to carry cable, most of the pulling being done by the power of the truck. If the job is too heavy for the truck, it may be anchored or blocked and the work done with the winch handle.

If not mounted on a truck or other carrier, the winch should have a V-shaped towbar, or a subframe by which it can be anchored. Blocks should be provided to build up a base in line with the pull, as, if this is high, the winch will be lifted off the ground and will not be steady enough to allow turning the handle.

MULTIPLE LINES

Snatch Blocks. If pulling stumps takes the full power of the tractor or winch, it may be advisable to use snatch blocks to obtain greater power at slower speed. These devices, also known as blocks and as pulleys, are pulleys set in frames that are provided with one or two round hooks or rings, usually on swivel connections. For most field work, single pulley wheels, with a latch arrangement permitting insertion of a cable at the side, are best, as cables usually carry attachments too large for threading; a tedious job even when possible.

These blocks can be obtained in sizes to

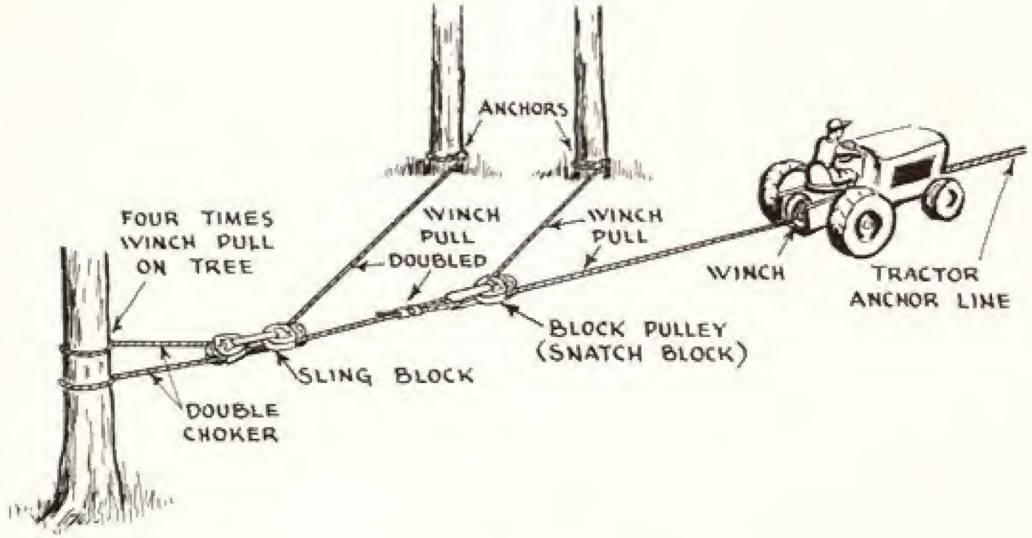


Fig. 1-18. Use of sling block

match any cable or strain. In large sizes they are very heavy, and several men, or a small wheel tractor, or light donkey winches may be used to move them.

Figure 1-17 shows several riggings using pulleys. If the lines are approximately parallel, and the pulley bushings lubricated, each additional line will add about 90 per cent to the single line pull. This puts no extra strain on the winch cable, but the chokers holding the blocks must take the combined pull of all the lines fastened to them.

The advantage obtained from the use of a block is decreased when the lines are not parallel, bcoming zero when the angle between the lines is 114°. Still wider angles result in loss of power.

The number of lines that can be put on one stump may be determined by the number of blocks on hand, the space available for fastening them, the strength of the available anchorage, or the amount of cable. Light machines may use six or eight blocks on a heavy stump.

Rigging is simplified by the use of series and sling blocks as in Figure 1-18, (A). The tractor line passes around a block pulley to an anchor, doubling the pull at the block frame. This is attached to a heavier line which passes around another pulley to an anchor. The second pulley is pulled with almost four times the power of the winch.

The sling block makes possible use of a double choker on the tree being pulled. The choker cable is approximately centered in the sling pulley, and both ends are hooked around the tree. Such a double choker can be of lighter and more flexible cable than a single choker.

Rigging. Multiple blocks require care in rigging and pulling. Two anchors are better than one as they spread the cables over a wider space where they are less apt to interfere with each other. Each block is best fastened to a separate choker, but one may be fastened to each end of a chain passed behind the stump if it is strong enough to take a double pull; or one to both ends of a chain given one turn around the stump. It is good practice to notch the stump for each chain used so that the chains and blocks will not slide into each other as it yields.

Rigging is done with the lines slack. When they are pulled tight an inspection

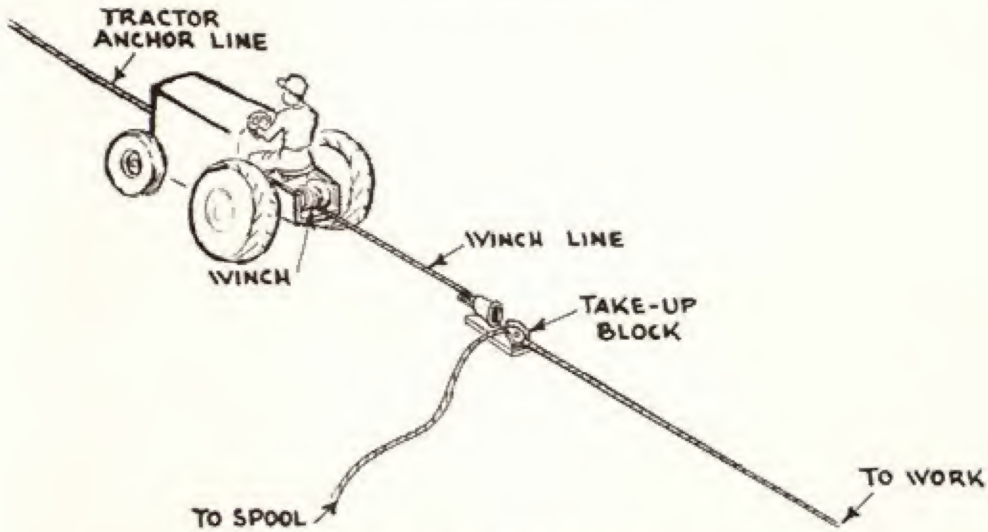


Fig. 1-19. Take-up block

should be made to make sure that no pulley latches have fallen open, as a pull on an open block will bend it and cut the cable; that no pulleys are jammed with debris, or liable to pull into each other, and that no chain hooks have become disengaged. As the line is wound in, all blocks should be watched to make certain that they do not collide. Lines should not be allowed to drag on each other.

If the winch does not carry sufficient line for the distance or the number of lines involved, extra line can be added by the use of a take-up block, as in Figure 1-19 (B). Standard practice is to use the winch line from the tractor to near the first snatch block, and the extra line for reeving. The take-up cannot be pulled through a snatch block, and is liable to cause trouble if included in the multiple lines.

The extra line is often carried on a spool supported on a pipe axle and brackets. This should have a drag brake of some kind to prevent spinning when paying out. The spool is sometimes mounted on a tractor or light truck, and the engine power used to reel in surplus cable.

Anchors. It is often a question of whether the stump or the anchor will yield. Anchor lines should be as low as possible and stump lines high. It may be best to pull the largest stumps first, using several smaller ones for anchorage if necessary. In a clean clearing job, there is always one last stump for which there is no anchor, and if it is small, it may be pulled out directly; or in any case it wil respond to less elaborate artificial anchors than a large one. On the other hand, a large stump will be a dependable anchor, and will prevent the need of frequent re-rigging when anchors pull out.

The final stump may be pulled by use of a living tree as an anchor. A choker should not be used under any circumstances on a tree which is to be preserved; padding and blocks should be used with a grabhook loop.

If no anchor is available, one may be made, ground conditions permitting, by digging a T shaped trench, two or more feet in depth, as shown in Figure 1-20. A log is placed in the crossbar, the cable anchored to it and led up through the sloping trench toward the work. Load and local conditions will determine the depth of cut and size of log. In medium soil, a standard railroad tie two feet down should hold a horizontal pull of five tons.

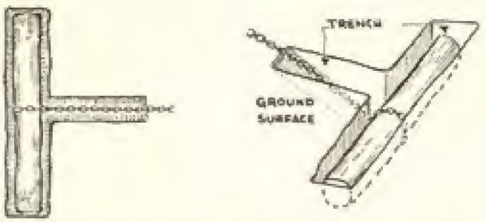


Fig. 1-20 Artificial anchor

Advantages of Blocks. Stump pulling with a winch and blocks takes more time and care than direct winch pull, but results are generally more satisfactory. Jerks and jars which are destructive to machinery and cables are largely eliminated. Lighter cable may be used and a sufficient number of lines will reduce the tension on any one so much that squeezing and crushing on the drum will not occur.

A snatch block may be used to advantage with an anchored winch to avoid shifting its direction for each stump. Figure 1-21 shows a plot in which a number of scattered stumps are to be pulled. A snatch block is anchored to one of them and the line led through it. The line can then be attached to stumps straight in line with the winch, or to any on the opposite side from the anchor, as the pulley will lead the line almost straight in, at the price of a small friction loss. The pulley is best placed at a moderate distance from the winch so that the cable can feed evenly onto the drum, instead of tending to pile up in the center. The line from pulley to anchor should be short to keep shifting of the pulley to a minimum.

PUSHING AND DIGGING OUT

Bulldozer. Trees and their stumps may also be pushed over or dug out by a bulldozer. The blade is raised as high as possible to contact the stump near the top, and walked into it in low gear. If the tree yields, the push should be continued until the blade loses effective contact, or the roots under the tractor bulge. The dozer

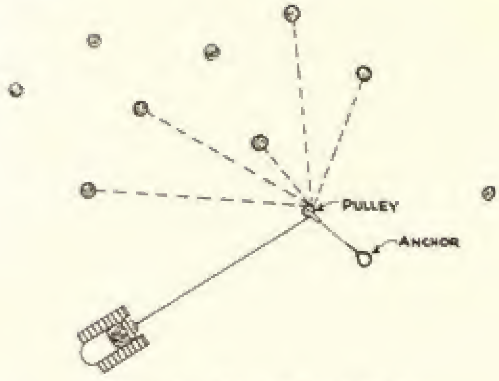


Fig. 1-21. Use of guide pulley

should then be backed and the blade dropped under the upturned roots. By moving forward gradually and lifting steadily, the stump may be rolled out of the ground, although extra passes may be needed to break all the roots clear.

A number of small trees may be pushed over at a pass, and the dozer backed to take out the upturned stumps on the next trip.

Before ramming a tree with any type of machine, the operator should look to make sure that it is alive or at least sound. If a rotten tree is pushed near the base it may break high up and a top section fall on the dozer. Large dead branches are sometimes dropped with equally disastrous consequences. A dozer to be used extensively for tree pushing should carry overhead guards for the operator.

A tree may bend or split without affecting the roots, in which case the push should be applied lower on the trunk, or from a different direction.

Digging Out. If it does not yield at all to pushing, it must be dug out. This is done by trenching around it with the dozer to cut the roots. If done systematically, this may follow the pattern in Figure 1-22, but it is frequently unnecessary to go through the whole procedure. Each time the dozer cuts a big root, it may turn and push the stump to see if it is loosened. The operator will often be able to tell when it has been

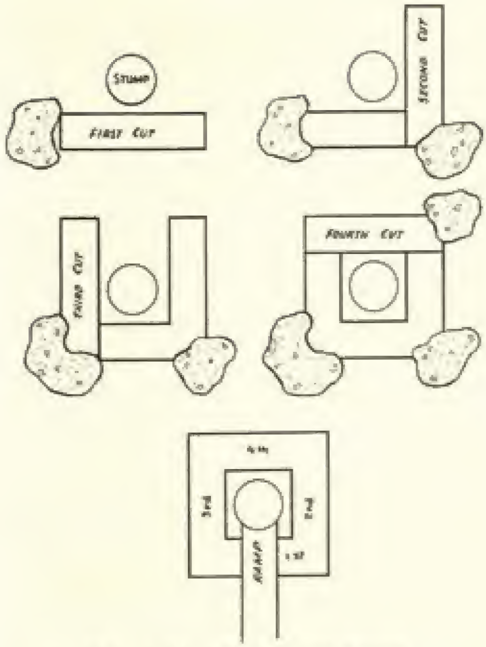


Fig. 1-22. Digging out stump

softened up by the way it shakes as the roots break. Many operators do not bother with cut number 4, but it helps with very heavy stumps, particularly when cut low. The ramp need be built only after an attempt to uproot from a lower level has failed.

Roots should be cut as close to the stump as the power of the dozer permits, but it is a waste of time and power to buck at a heavy root repeatedly when it could be easily broken a foot or two farther out and the stub crumpled back.

Pushing over a stump may leave a hole so large that the dozer cannot cross it to complete the tearing out. In this case, the dozer may be stopped at the edge with brakes locked and the blade holding the stump up. The operator can climb down and block the stump from settling back with stones or a log, then back the machine and push dirt into the hole, or break down its edge so that it can walk into it.

If an area is to be excavated after clearing, stumps may be left until digging has undermined them and cut many of their roots when they can be easily removed.

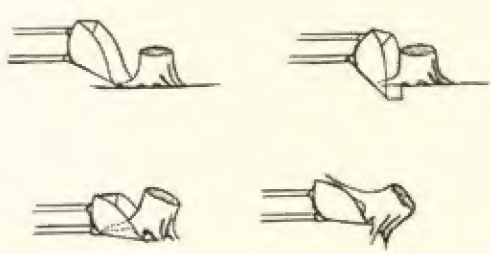


Fig. 1-23. Stumping with shovel dozer

Shovel Dozer. A shovel dozer can remove stumps in the same manner as a bulldozer, or make use of the hydraulic control bucket in special techniques. A stump of small to medium size may be dug by tilting the bucket floor downward from thirty to sixty degrees and forcing it into the ground close to the stump, as in Figure 1-23, using both down pressure and forward motion. With the machine pushing forward, the bucket is then flattened and may be driven under the stump, cutting and tearing the roots, and then lifted, breaking the stump out of the ground. If it falls off, the bucket is dropped to contact it and to roll it out of the ground. If it stays in the bucket, it can be carried to a pile or loaded directly on a truck.

The high lift gives the dozer shovel excellent leverage for pushing over trees.

Bucket teeth are desirable for stumping as they aid penetration, get a better grip on the stump, and are useful for knocking dirt off the ball, and for raking out roots.

Methods of handling stumps with a dozer bucket are described in Chapter 16.

Selection of Machinery. Big machines, and special machines, greatly reduce time, effort, and breakage in clearing work, and should be used whenever a job is large enough to justify their purchases or hire. Stumps that can be knocked right out of the ground may be removed at the rate of one a minute or better; moderately resistant ones may take two to five minutes; and those which are definitely oversize may

take an hour or more. It is easy to see the time that can be saved by applying overwhelming power.

A good clearing team may be made from a heavy tractor with a stumper, assisted by a smaller one with a shovel dozer. If these machines work together closely, the stumper can devote its entire time to breaking out the big ones, while the dozer takes out small stumps, knocks down brush, finishes off loosened stumps, piles and removes them, and smooths off the ground.

Revolving Shovels. The backhoe is probably the best stumper among the shovel attachments. Usually, the operator tries to take the stump by a direct pull first. If it resists, it can be weakened by chopping roots on the far side and by trenching at the sides. Except in the case of very large stumps, digging and removal can be done from one position. It may be necessary to put blocks against the tracks to prevent the shovel from dragging toward the stump when power is applied.

A dragline is used in the same manner but is less efficient at chopping roots, and does not have as strong a pull. However, it can often take out a number of stumps without changing position, and is able to backfill the holes and grade the area at the same time.

A dipper stick is used in somewhat the same manner described for a dozer shovel. It has more penetration and can trench to cut roots more readily but is less maneuverable.

The hoe and the dipper are more effective than dozers in rocky ground and among interlocked stumps as they can apply their power in smaller spaces. It is often necessary to devote time to digging out rocks before the stump can be attacked. If the roots are strongly entrenched in bedrock or over-size boulders, the rock may have to be blasted before the stump can be pulled.

Rippers and Pans. Rippers may be used to cut stump roots and to dig out stumps directly if they are low enough for the ripper frame to clear. The teeth are lowered into the ground, pulled under the stump, and raised as the forward motion continues. Two teeth are generally used.

Scrapers may be used in much the same manner, the edge getting under the stump and lifting it out. It may also be possible to leave the edge low and to scoop in the stump with a chunk of surrounding earth. However, a stump may become wedged into the bowl so as to be very difficult to eject.

If the stump is low enough the tractor can straddle it. If it is high, the tractor should pass close on one side, then cut over sharply so that the blade will contact it.

Hand Digging. Often trees are so located that uprooting them would damage pavements or buildings so a trench must be dug around the tree by hand, and the main lateral roots cut. This is a very tedious job as much of the dirt between the roots must be dug with a trowel, or even with smaller tools. If space is available, the roots may be chopped with an ax, but a hatchet or wood chisel and hammer may be better.

After the main roots are cut, the smaller laterals are liable to break so that the trunk will come out with very little heaving of the soil. If a taproot is present, it may be cut with long chisels while pulling. Any tendency to heave will show the presence of heavy roots which have not been cut, so that further digging and chopping may be required. This same technique may be used to weaken trees or stumps that are too resistant for the pulling power available.

Men accustomed to grubbing out stumps by hand can do the job in a fraction of the time required by ordinary laborers.

Tree Killing. Under most conditions dead stumps are easier to remove than live ones because of the disappearance of the hair roots which bind them to the earth, and the weakening of the larger roots. Soft

woods in well drained soils may show perceptible weakening in a few months, while rot resistant stumps in saturated ground may remain firm for many years. In any case, dead stumps contain lighter wood and hold less dirt than live ones.

It may therefore be advantageous to kill trees well in advance of removal in cases where plans are made early enough. This may be done by cutting, girdling, poisoning, burning or drowning. Cutting and girdling are ineffective with trees that sprout from the stumps, unless the sprouts are cut back several times, or poison is inserted under the stump bark. Poisoning may be done without cutting by nicking the tree in late summer or fall and putting sodium arsenite or weed killing chemicals in the cuts. The same methods are not equally effective in different localities so advice should be obtained from local tree experts.

Burning peat soils in the dry season will kill trees and loosen the stumps, but because of smoke and smell nuisance, and danger of spreading, it should be done only under carefully controlled conditions.

If it is possible to dam a stream so as to flood a wooded area for several months during the growing season, some or all of the trees may be killed. Unfortunately this is usually póssible only in swamps, and swamp trees are more resistant to drowning than those in dry locations.

Burning Stumps. Partially rotted stumps may be difficult to pull because they fall apart. These should be pushed or dug out, or burnt.

The best tool for burning stumps is a large kerosene blowtorch. It may be blocked up and left turned against a stump, and one man can operate several of them, or do other jobs while taking care of one. When the wood starts to burn, the torch may be moved to another stump and brought back if the fire dies down. Green wood will require continuous heat for many hours.

The torch will operate most effectively if directed into a cavity with an opening in the far end so that a draft can move through it. If the flame is aimed into a dead end hollow, very high temperatures will be attained, but because of lack of oxygen the wood will distill rather than burn and will be destroyed slowly. If the flame is used against the outside of the stump, it should be directed upward to draw a current of fresh air between the flame and the wood.

Dry stumps may also be burned by starting a wood fire alongside them, and keeping it supplied with logs and snags placed to almost touch the stump. The draft and reflection of heat will keep both surfaces burning, but the loose wood must be moved in rather frequently. This method may remove only the top and outside of the stump, leaving a conical core.

Care should be taken to avoid spreading stump fires. Roots may burn underground to start surface fires at a distance. Soils rich in humus, such as swamp peat or forest loam, may burn unless saturated with water, and are very difficult to extinguish.

Disposal. Fire is the only stumping procedure that avoids the problem of disposal. Stumps, except in very small sizes, are too heavy and bulky for convenient transportation or burial, are often too green or filled with dirt and stones to burn readily, and are too unsightly to be left around. They can be buried in very deep holes, often dug for the purpose; but they are not suitable fill for support of engineering structures. Because of their awkward shape, the hole should be deeper than their longest dimension unless they can be lowered to position with a crane. Handling will be simplified by cutting all roots back as far as possible.

Burning is the usual method of disposal. A hot fire is built and the stumps pushed or lowered into it as they are taken out, or after they have been allowed to dry for a time. In localities with sticky soil, it may

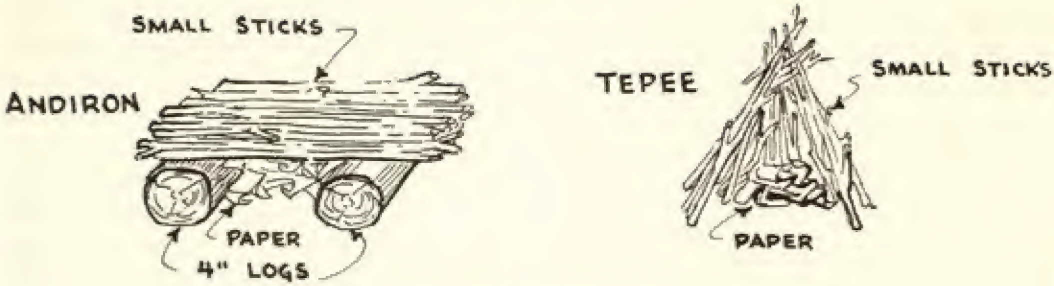


Fig. 1-24. Starting a fire

be necessary to blast the stumps before pulling to avoid choking the fire with excessive amounts of dirt. Another way to reduce the dirt ball is to overturn the stumps and leave them with roots exposed for a few weeks, then finish knocking them out of the ground when the dirt is drier and falls off more readily. Dirt may also be dug out of them with hand tools.

Instead of putting the stumps directly on a fire, they may be piled up and allowed to dry for six months to two years, then burned. Such a heap may be difficult to light unless piled on brush or other kindling, but once any part of the pile is burning strongly, the fire should spread to other parts readily. Stump fires are very hot and burn for weeks.

BURNING BRUSH

A great deal of time and effort are wasted in ineffective attempts to burn brush, and for this reason proper procedure will be discussed in some detail.

Even green, wet brush and logs will burn vigorously once properly started, but considerable heat is required to boil off the sap and water, and to ignite the wood. This heat may be obtained originally from a carefully built fire, or by use of inflammable chemicals.

Building a Fire. The fire should be on level ground, or on a hump. If built in a hollow or against a rock or stump, inward flow of air will be hindered, and brush added to the top of the fire will be held up away from the heat. All inflammable material should be cleared or burnt away from around the site, particularly downwind. Fire fighting tools should be available.

Figure 1-24 illustrates two ways of starting the fire—andirons and tepee. The "andirons" consist of a pair of small logs, or rocks, or ridges of dirt. Twigs and sticks, preferably dry, are laid across the andirons. These should be laid in one direction so that they will lie close together, but should not fit together so well as to prevent air and heat going between them. No leaves or grass should be included.

This pile is ignited by burning paper, dry grass, or chemicals under it, renewing the fire until the sticks burn briskly. More and heavier sticks are added, then partly trimmed branches, and finally, when a good bed of embers and strong flames are present, untrimmed bushes and branches. It is a good plan to put a few logs or snags on at this time to give the fire staying power.

The tepee is similar in principle. The sticks are piled on end around the kindling. As heavier pieces are added, the tepee is crushed, but if it is burning well this will not matter.

A danger in transition from the hand tended fire to the roughly piled one is that the untrimmed brush may include so much air space that the heat cannot cross it effectively. The fire may burn a dome shaped hole over itself, then die down. In such a

case, sticks should be poked into the fire itself to build it up, and the brush over it should be compacted by rearrangement or piling on of heavy sticks. This is tiresome work and may fail. It is better to tend the fire longer before piling on loose material, to be sure it will not have to be worked over afterward.

Artificial Helps. Old tires provide excellent material for starting a fire. Trimmed brush can be piled on them as soon as they are burning.

A dying fire may be pepped up by use of kerosene, fuel oil, gasoline, or similar fluids. To be effective, these must be applied at the base of the pile. Because of its explosive qualities, gasoline should be applied only as a stream from a blowtorch or similar pressure device with a fine nozzle, and only when it burns as it is ejected. If it does not burn, it may accumulate in sufficient quantity to cause an explosion.

Putting inflammable fluids on the heap itself may produce a fine flame, but it will have little kindling effect as the evaporating fuel will absorb the heat that radiates downward.

Large kerosene blowtorches, called flame guns, may be used to advantage. A hot flame six inches in diameter and twenty inches long can be obtained from some models, and when directed into the base of a compact pile of brush, should be quite effective. It can also be used cold to spray fluids into the bottom of the pile.

If the fire dies down in spite of nursing, it may be best to build a new fire nearby, with greater care to avoid air spaces and coarse green wood early in its life.

Transferring Embers. Once a good fire is burning on the job, its embers may be shoveled out and used for starting other fires. This should be done rather frequently as a long brush carry adds greatly to labor costs.

Four or five shovels of hot embers may be laid on the ground in a pile, and fine brush, or dry twigs and wood, piled on it. Or the embers may be sifted down through piled brush. The embers give a sustained heat and consume little oxygen, so that a strong new fire starts quite quickly.

Feeding. It usually takes at least two men cutting and dragging brush to keep one fire burning briskly. If it is allowed to burn down, it is good practice to put the unburned ends in the center hot spot, before piling on more brush.

When a dozer is used, ample supplies of fuel can be brought to the fire, and it is usually well packed by the pressure of the blade and the weight of the machine if it climbs up on the pile.

The principal problem of dozer feeding is dirt. This tends to block the fire from spreading into new material, and to smother parts already burning. Every effort must be made to reduce the amount of dirt by rolling and jostling piles, holding the blade high enough not to dig in, and giving the vegetation and mud a chance to dry before bringing it in.

A hot fire will burn through quite a lot of soil, but it will seldom burn clean. After it cools, the remaining stems and stumps can be sifted out by the dozer and used in building the next fire.

Best results in fire feeding are obtained if at least part of the new material can be placed on top of the flames.

Banking Fires. If the job is not extensive enough to justify the employment of a night man to watch the fires, and any inflammable material is nearby, they should be buried under a few inches of clean dirt at the end of the work. Humus or rich topsoil should not be used. The soil cover will prevent sparks from blowing, preserve a hot bed for use in the morning, and, if the cover is not removed, may make a fair grade of charcoal.

Burning Piles. If the brush is piled a long time before being burnt, dropping a match in it on a hot day may accomplish its com-

plete removal. If it has been piled only a few hours or a few days, a fire may be built on the windward side against it but not under it. This fire may be caused to spread into the heap by keeping it buried under compact brush, so that the fire is fed and the heat reflected into the pile. If the brush has leaves, it is good practice to cover any place where flames show through. A strong fire cannot be smothered with hand piled brush.

Brush piles may be pushed on top of fires by a dozer, placed by a clamshell, or rolled on by a number of men using long poles.

If brush is being cut in an area presenting unusual fire hazard, or the cutting is in small, scattered areas, it may be desirable to truck it to a central burning place. A continuous fire may be maintained with incoming loads dozed or hand piled onto it, or the brush may be piled to dry and burnt off occasionally.

Brush up to a few inches in diameter can be reduced to chips by a chopping machine after which it can either be left on the ground or easily trucked to a dump.

FIRE CONTROL

Any contractor burning brush in an area subject to brush or forest fires is subject to heavy responsibility if one of his fires spreads. Also, in the presence of extensive forest fires from any cause, the contractor may be required by authorities to use his men and equipment to control them. At such a time there might not be experienced fire fighting personnel available to direct his work. A brief outline of fire fighting techniques is therefore considered appropriate.

Hand Tools. Where the material burning is largely grass and associated weeds, or thin brush, fire can be beaten out. Household brooms, occasionally dipped in water if possible, are very effective. Shovels or leafy bushes or branches can be used with good effect. Each blow should be directed so that flying sparks are knocked toward the burned area.

The fire may also be starved by scraping away the vegetation just beyond the flames. This may be done with shovels, hoes, rakes, grub axes, or almost any piece of metal. A special type of fire fighting tool, shaped like a heavy rake and fitted with sickle bar teeth instead of tines, is quite effective. Bushes may be cut with axes, machetes, bush hooks, or pruners.

Extinguishers. Back pack fire extinguishers, which consist of a water tank carried like a knapsack, a flexible hose, a hand pump, and a nozzle are important pieces of equipment. If the grass is low or thin, spraying in the path of the fire may stop it. If the fire is strong and moving rapidly, the water may be most effectively used for putting out smoldering spots behind the beaters. Addition of a wetting agent—a small quantity of synthetic powdered soap will do if regular compounds are not available—increases the effectiveness of the water by enabling it to soak through vegetable litter and punky wood.

Pumps. If streams or ponds are available, the contractor's pumps, particularly the light centrifugal type, are very valuable. A welder or machinist can usually make adapters quite quickly that will permit fire hose to be attached to the pump outlet. The high pressures used in regular fire pumps will probably not be developed, but sufficient pressure will be available for wetting down firebreaks, or making direct attacks on anything short of a crown fire.

Sprayers. Tree spraying outfits make good fire fighters. These usually consist of a tank holding from two to five hundred gallons, a high pressure pump driven by a small gasoline engine, or by the power takeoff of a towing tractor, or a carrying truck; a reel of hose, and a nozzle. Those having an engine are generally mounted on a wagon chassis that can be towed by

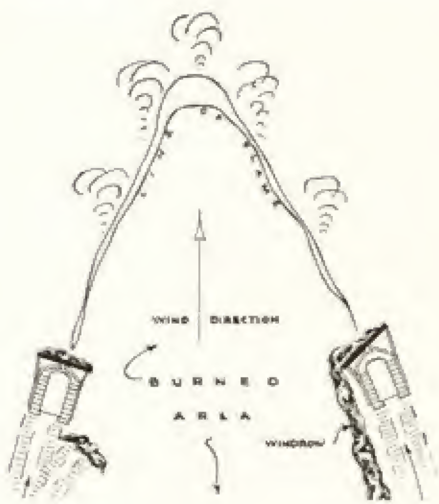


Fig. 1-25. Fire-fighting with dozers

almost any motor vehicle. If the pump is tractor driven, adaptation to most wheel tractors can be made quickly. The handiest models are those mounted on a motor truck.

Such equipment can generally be rented or borrowed in almost any area. The volume of water delivered through the nozzle is small, but pressure is high and results are usually excellent.

Dozers. A bulldozer can put out a grass fire by starting behind the fire and straddling its line as in Figure 1-25. It may be able to scrape off the grass without cutting much into the ground. If this is not practical, it can skim off the sod until the load is heavy, then swing it into the burnt area, or raise the blade and spread the sod over the next few feet of flames, smothering them. An angle dozer can side cast the sod into the burnt area, and a hand beater, or extinguisher, should follow to put out any spots that are missed.

Method of Attack. Windblown fires should not be attacked directly at the front as this procedure is both dangerous and ineffective. A new fire running before a wind will assume a shape similar to that in Figure 1-25. A direct attack on the front means fighting flames several feet deep. If these should be put out, fire blowing up the sides could rekindle them in a few seconds. A crippled man or machine ahead of the fire could not escape being burned.

Pinching off the sides is both effective and reasonably safe. The fire is extinguished starting at the back so that the heat and smoke are blown away from the workers. Provided a constant watch is kept behind them for rekindled spots, the fire cannot repossess the extinguished area. When the front is reached, it is attacked from directly behind as well as on the sides.

If the fire is too strong for the force fighting it, the front will continue to advance, but the work on the flanks will limit its width and make easier the task of stopping it with firebreaks or backfires, or after a shift in wind direction. It can sometimes be turned by concentrating on one flank.

Firebreaks. A firebreak is any strip bare enough of inflammable vegetation to delay or stop the spread of fire across it. Roads, open water, plowed fields, close cut lawns, and even footpaths may be used. In addition, breaks may be prepared in anticipation of fire along the crest of hills or mountains, at property lines, or at the edge of the areas being cleared.

Advantage should be taken of any existing breaks when deciding where to place one to stop a fire already burning. A short line is preferable, and valuable property or highly inflammable areas should be protected. The break should be far enough from the fire to allow time to finish it and to start backfires; it should be in vegetation least apt to make a spark-producing or a high fire, and on terrain favorable to operation of machinery. A compromise among these features must usually be made.

A bulldozer may be walked along the line of the break, alternately cutting and filling, so as to mix the vegetation with dirt. Hand workers with cutting or digging

tools follow to cut out any spots where fire might cross. If the brush is heavy, the dozer may turn to push heaps of it out of the path. An angledozer or a heavy grader might be able to make a single clean cut in each direction, turning the sod and brush out from the center.

In grass or light brush, a plow or heavy disc harrow might do a better or faster job than a dozer. The plow makes a rather narrow strip with each trip, and is subject to jamming with brush but does not have to go back over its work. A harrow may require several trips and might not be effective.

The hand tools listed earlier may be used to build a complete break, or to work one over after the machinery has passed.

Backfires. A strong fire adds to the force of the wind which is moving it, somewhat as a blowtorch builds up its fuel pressure. The combined force may be enough to project a sheet of flame many feet in front of the burning line, and to shower sparks for long distances ahead. For this reason, the fire may cross a break of any practical width and make the area too hot for fire fighters.

The principal use of the firebreak is to provide a line from which backfires can be started. Since the break is made on the downwind side of the fire, a new fire started on that edge burns upwind. The backfire should be made in a continuous strip along the break so that it will not be able to turn and blow back toward it. It will increase in strength as it progresses, but will be steadily farther away from the protected side. When it meets the main fire, there is liable to be a spectacular flareup and heavy production of sparks. If the backfire has been started in time, this should be far enough away from the break so that few sparks will cross it, and those can be extinguished by men patrolling the break. If no shift in wind occurs, the sides of the fire can then be put out by the crew working from behind, aided by the firebreak crewmen.

If the break is made in a forest where the flames might crown (burn in the tops), the trees on each side of the break should be bulldozed or cut so as to fall away from the center.

Since a change in wind direction may occur at any time, care should be taken not to start backfires prematurely, and to keep men and machines in positions where they can get away if the fire turns toward them. The burnt-over area, ponds or wet swamps, plowed land or well grazed pastures, are suitable retreats.

Men on the fire lines must be kept provided with food, water, and tools, and relieved for rest periods. Machinery must have fuel but may be skimped on other maintenance in sufficiently dangerous situations.

Backfiring, and possibly other phases of fire fighting, may be regulated or prohibited by local laws.

Re-Kindling. After the spreading of a fire has been checked, it must be patrolled until all danger of its making a fresh start has passed. A grass fire in a clean field may be safe to leave within an hour, while wooded areas containing dead or fallen trees, or rich dry soil, may be dangerous until after several soaking rains.

Dead stumps may burn a long time and are difficult to extinguish unless ample supplies of water are available. Fires burning under and between logs on the ground can often be put out by moving the logs apart, or can be caused to burn out more quickly by piling additional wood on them.

The worst hazards are standing dead or hollow trees, called snags by the lumbermen. If close to the line, snags may set fire to the unburned area by falling into it. They frequently produce sparks that may drift long distances. Even thorough soaking may not extinguish them, and it may be necessary to cut them down or maintain an expensive patrol for days or weeks.

Cutting a burning tree is a tricky and dangerous job as the cutters are in constant danger of being hit by falling pieces, and temperatures at the base may be too high for them or their tools. This job is best left to experienced fire fighting crews.

Snags may be pushed over by bulldozers but the tops are apt to fall on the machine. An overhead shovel, because of its heavy roof, gives good protection to the operator.

The best time to check a burned area for hot spots is immediately after a rain, or a heavy dew, as the moisture near the fires will steam.

Underground Fires. Underground fires, such as occur in rich forest soils and dried out swamps, constitute a special problem. When fire gets in them, often by smoldering down a dead root, they will burn hot and persistently. Plain water has little effect on such a fire unless applied in such quantities that the area is flooded. Smaller quantities do not penetrate the deeper burning zones, which have sufficient heat to evaporate quantities of water from surrounding peat, and then spread through the dried material.

Special nozzles consisting of pipes long enough to reach the bottom of the fire are helpful. The lower end is plugged and a fairly large hole is drilled in the plug to wash humus out of the way as the pipe is pushed down, and smaller holes in the side spread a soaking spray. The use of wetting agents will substantially reduce the amount of water required, and may make the difference between success and failure where the water supply is limited.

Such a fire may be confined by trenching down to inorganic or saturated soil. The digging may be quite difficult because of roots, and a backhoe or dragline shovel might have to be used.

Peat fires spread very slowly unless they ignite surface vegetation or litter which set fire to the soil at new points. If equipment is not immediately available to extinguish or ditch the fire, leaves and inflammable trash should be removed for ten or more feet around it, to prevent rapid spreading while arrangements are made to put it out.

BOULDERS AND BUILDINGS

Boulders. An area may be so strewn with loose or partially buried boulders that work is difficult, and the removal of these rocks may properly be considered clearing.

If large enough machinery and suitable disposal points are available, the rocks may be turned or dug out and pushed away. If they are too large for easy handling and disposal, it is usually advisable to dynamite them down to size.

If blasting techniques are not to be used, rocks may be reduced by means of air or sledgehammers, and wedges, or by drilling and using plugs and feathers. The plug and feathers consist of a pair of hard steel pieces, half cylinders, whose outer surfaces are curved to fit inside the hole, and whose inner flat sides are separated enough to permit a thin hard steel wedge to be driven between them with a sledgehammer or paving breaker. The very gradual taper of this wedge exerts a tremendous splitting force, and in the hands of an expert and energetic man can be used to split large and stubborn boulders.

Under many circumstances, however, a contractor may prefer to get rid of the rocks by digging and pushing. The dozer is the standard tool for this work. Efficiency can be increased by use of a tilting blade, a dozer shovel bucket, a stumper, or a heavy duty rake blade.

A dozer can move quite a large rock on firm ground, perhaps several times its own weight. If the stone is too large for direct pushing, it can be pushed first on one side, then on the other, as in Figure 1-26. If it is rounded, it can be rolled by lifting the blade while pushing. If the blade does not have enough lift to roll it over, it can hold

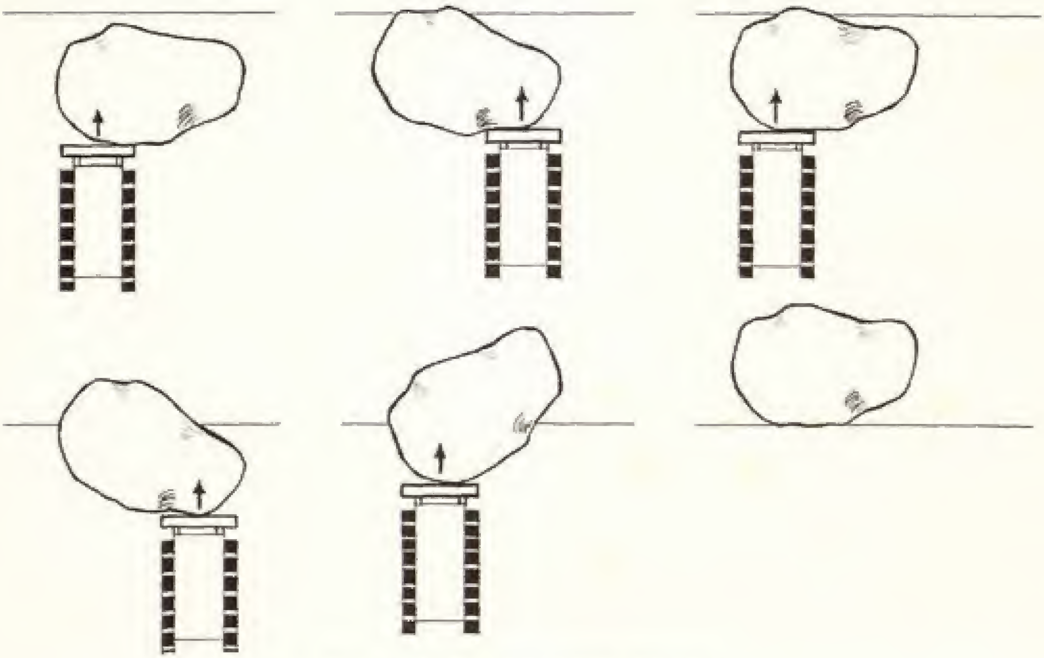


Fig. 1-26. Pushing oversize boulder

it in a partially rolled position, with locked brakes, while the stone is blocked up. The blade may then be lowered and the push and lift repeated.

Partly buried rocks may be pushed or dug out in somewhat the same manner as stumps. The resistance they offer is usually more rigid and brittle than that of stumps, and if a rock will shake in the first few direct blows of the blade or bucket, it should come out. It is sometimes very difficult to get a grip on smooth sloping surfaces, so that an excessive amount of digging must be done just to get a hold.

When a grip is obtained with a dozer blade, the rock may be raised and pushed. If it is backed by unyielding material, the engine clutch should be slipped so as to supply just enough forward pressure to keep the blade in contact with the rock while it lifts it vertically, and, when it is high enough, rolls it out. The rock may slip back into its hole at any time, and it is good to have a helper throw stones or logs under it so the blade can be dropped and a fresh grip obtained. If no helper is available, the operator can lock the brakes to hold pressure against the stone and do the hole filling himself.

If a big stone is rolled out without blocking, it may leave such a large hole that the tractor may be damaged if it falls in it. The danger is more serious than with stumps as rocks leave sharper edged and harder holes.

A rock should be pushed from all angles before digging it out as it may be susceptible to pressure from only one direction. If it is to be dug out, a bowl-shaped crater of considerable size is excavated, working on three sides, if a good grip is available at the top, or all around it if the top is smooth. When it is finally loosened, it may be found that it is so heavy that the dozer cannot get it up out of the hole.

It probably can be pushed out by following the procedure outlined in Figure 1-27. The dozer builds a ramp out into the crater, shaped so that the machine will be pitched downward when its blade meets

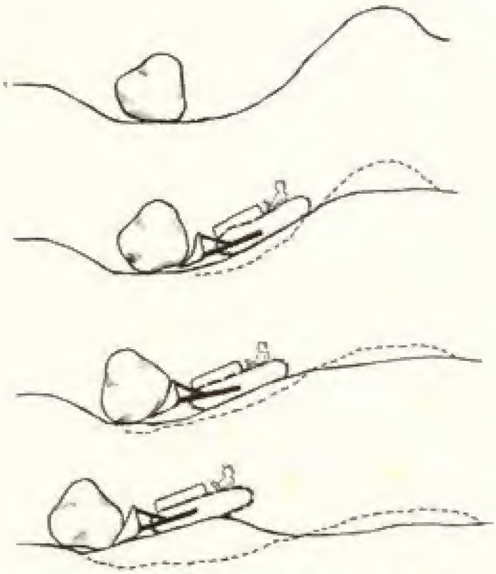


Fig. 1-27. Getting boulder out of a hole

the rock. With gravity assisting, it should be able to push the stone a short distance up the opposite slope. The ramp is then built out, and another push made until the stone is out of the hole.

Loose boulders may be pushed out of the work area and scattered, piled, or arranged in walls; or they may be buried, being either used as a fill or wasted in holes. Holes may be dug to bury them.

Where many boulders are pushed into a hole they afford unsafe footing for a bulldozer and may pile up above the desired grade. A moderate amount of dirt, either scraped off the bank or trucked to the spot, will allow the dozer to fill in the holes and stabilize the rocks so that it can walk across them in pushing other boulders to their resting place.

If the area is to be finished to a grade, it pays to be liberal in supplying covering soil, for if the layer is thin the dozer working on it may hook into freshly buried rocks and turn them into high positions. They can seldom be put back in place because of soil and other rocks getting under them, and it may be necessary to knock their tops off with hammers or explosives, or dig them out and rebury them. Digging a boulder out from among others is very difficult and it is likely to turn them up also.

Rocks may also be trucked away from the job. They may be picked up by shovel, by clamping in a clamshell or orangepeel bucket, or balancing on a dipper or hoe bucket, or by tongs or chaining. Light chains, or cable slings, are best for getting a grip, but are more subject to damage and breakage than heavy chain.

Ordinary light dump truck bodies are liable to be seriously damaged by oversize rocks. The floor may be protected by laying or bolting down planks.

Stone Walls. Stone walls built to dispose of boulders removed from farm land are very common in some sections of the country, and may include rocks large enough to present a problem to machinery. The big base stones are often partly or completely buried, interlocked, and bound in place by tree roots. The smaller stones may be valuable for use in masonry, and may be removed by hand before or during the wrecking of the wall.

A dozer of sufficient size can walk right through the wall and scatter it around, but an undersize machine may have to start at a gateway, or find a weak spot to break through and widen the hole by worrying the rocks out one at a time. If the wall cannot be broken from one side it should be tried from the other.

Foundations. Old foundations and other masonry structures usually yield readily to heavy machinery. High walls should be pulled down as they might fall on a machine pushing them.

If a foundation is too strong for available machinery, it may be weakened by blasting along the lines where it meets the floor and other walls, by mudcapping or drilling. Demolishing very heavy or extensive structures, however, is a house wrecking job out of the field of this book.

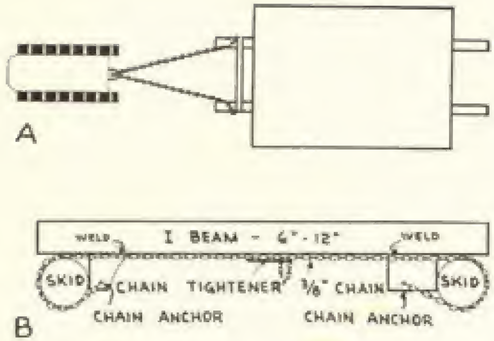


Fig. 1-28. Bracing tow skids

Small Buildings. Moving buildings properly is also a highly specialized trade, but an excavating contractor may be called upon to move small buildings of minor value out of the work area, or to drag his work buildings around on a job.

The easiest method is to jack the building up, or to lift it one end at a time with a shovel or crane, and pull a pair of substantial skid logs under it. These should be beveled at the front so as not to dig in, and notched on the top for the sills of the building. They should be spiked or bolted to the sills. If the building needs additional rigidity, cross logs may be used above the skids and the walls may be braced with diagonal planks.

The skids should be rigidly fastened to each other. If the building is to be pulled by one machine, through a double chain as in Figure 1-28 (A), which is the usual method, the bracing between the front of the skids takes a tremendous inward pressure. Ordinary log or timber braces may not hold, unless very expertly installed, or the pull is light.

It is usually worth while to make a steel cross brace such as is shown in (B). The beam itself may be second hand I beam, or channel or angle. The welded brackets prevent the skids from moving inward, and the chain, pulled tight with a load binder, prevents them from moving out. Notches in the bottom of the skids are necessary to prevent the chain from cutting into the ground and increasing the draft.

The skids should project far enough forward to be easily chained for pulling or lifting. They should be high enough to carry the sills or cross logs over any irregularities in the ground. If this is not practical, rollers, consisting of short logs, may be put under the front of the skids. As the building goes over these, they must be watched so that they will not turn up and injure the structure. When they are left at the back, they may be picked up and carried to the front.

Rollers are also used when the tractor is not powerful enough to pull the skids on the ground.

CHAPTER TWO

LEVELS AND LOCATIONS

GENERAL CONSIDERATIONS

Surveying is a profession in itself and contractors and their employees seldom have time to master it. However, it is possible for a layman to run levels, to re-establish lines and locations obliterated by construction, and do rough layout work.

If a job involves as much as a day of work for a surveying crew, it is usually economical to hire professionals. They work more rapidly and efficiently than amateurs, and are less liable to make costly mistakes. Unfortunately, it is frequently not possible to obtain the services of engineers exactly when needed, and there are many jobs which are too small, or too simple, to justify calling them in.

Also, it is sometimes dsirable for the owner or contractor to make a rough survey of a project to determine the amount of work to be done, and possible layouts, before bringing in surveyors to provide detailed information. A man can usually obtain a much clearer idea of the problems involved by running his own levels than by reading the findings of another.

The methods outlined in this chapter will in some cases be those used by surveyors, but will often be shortcuts and substitutes which can be used by amateurs with reasonably satisfactory results, and which generally are easier to learn, but less accurate, than professional methods.

More detailed information about surveying may be found in textbooks on plane surveying, such as are used by engineering students. A few months' work with a surveying crew is about the best training in field methods.

TELESCOPIC LEVELS

The basic surveyors' tool is a telescopic level mounted on a turntable which in turn is usually supported by a tripod. There is a great variety of these instruments, but most of them may be classified under three headings—level, convertible level, and transit. The difference is partly that in the first the telescope is always used in a horizontal position; in the second the telescope may be lifted out of its frame and reset so as to pivot vertically; and in the transit it is permanently mounted so as to swivel vertically as well as horizontally. However, these general distinctions are not always true in regard to particular models.

Builders' Level. Figure 2-1 shows a type of builders' level which is convenient for general contractors' use. The telescope is held rigidly in a U Frame that rotates on a vertical spindle, which is perpendicular to the line of sight of the telescope. A spirit level with a graduated glass is mounted on the frame.

The leveling head on which the spindle rotates is shown in Figure 2-2 fitted with a horizontal circle marked in degrees, in contact with a pointer fastened to the

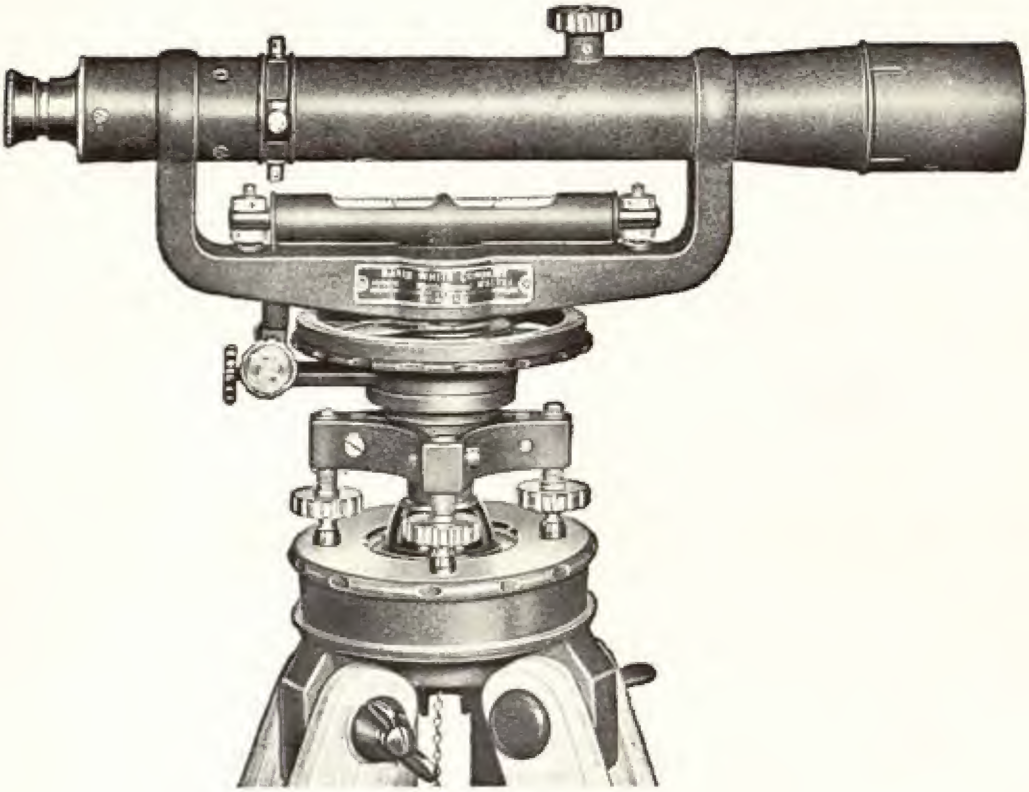


Fig. 2-1. Builders' level

spindle. Many levels do not have this circle, but it is essential for the location work to be described.

Fig. 2-2. Horizontal circle

Vernier. The pointer may be expanded into a vernier such as shown in Figure 2-3. This is a device for reading fractions of a scale, which in the example is calibrated to 30′ (half degree) divisions. The length of twenty-nine divisions on the circle is divided into thirty divisions on the vernier. Each vernier space therefore represents 29/30 of a space on the circle, and is 1/30 shorter.

In the illustration, if an angle on the main scale is being read from left to right, the zero, or center of the vernier, shows a reading slightly higher than 2° 30′. Reading the vernier to the right, it will be found that the tenth division line matches exactly with a line on the circle scale. This indicates that the zero mark was 10/30, or 1/3, of the way from 2½° mark to the 3° mark, as the difference is cancelled out in the course of subtracting the 1/30 difference 10 times.

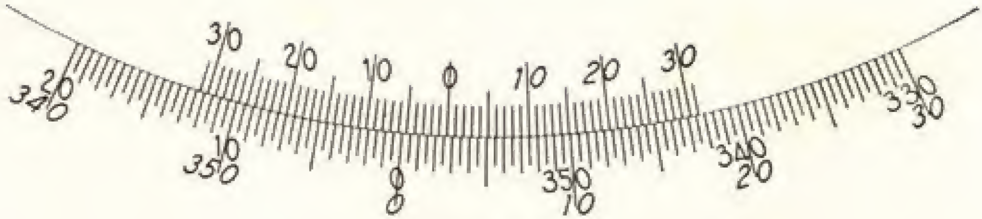


Fig. 2-3. Vernier

One third of 30′ is 10′. The angle is therefore 2° 30′ plus 10′, or 2° 40′.

If the angle were being read from right to left, the main scale would read 357° and a fraction. Reading the vernier to the left, the twentieth division is found to correspond with a line on the circle. The angle is therefore 357° plus 20/30 of 30′, or 357° 20′.

The telescope may be locked against swinging by means of a thumbscrew for convenience in reading the scale, or holding it in a certain direction. Another thumbscrew will then move it slowly for fine adjustments.

Telescope. The length and power of the telescope and the length of the spirit level, determine the range of the instrument and, to a considerable degree, its accuracy. Telescopes range from ten to eighteen inches in length, and from ten to thirty-five power in magnification. Spirit levels may be three to ten inches long.

The telescope is focused by means of a knob on the top, and usually by a turning eyepiece also.

The field of view of the telescope is divided into quarters by the cross hairs, shown in Figure 2-4 (A), which are held in a frame or diaphragm inside the telescope. Provision is usually made to make these visible or invisible by focusing the eyepiece. The horizontal hair is used for taking levels. If it is correctly placed in the telescope, and the telescope is properly leveled, it indicates the slice of the field of view which is level with the observer's eye. The vertical hair is used to sight a given point or line, and indicates the exact center of the field of view for determining horizontal angles.

Stadia Hairs. Stadia hairs (B) may be fitted into the same frame. These are horizontal and are located above and below the center hair. The distance between the stadia hairs is fixed at a ratio with the telescope, usually 1 to 100, so that if a measuring rod is sighted through the scope, the inches or feet seen between the stadia hairs may be multiplied by 100 to give the distance of the rod from the instrument.

Amateurs are apt to confuse one or the other stadia hair with the cross hair in taking levels, with resultant serious error. If this trouble persists, additional hairs may be installed, as in (C) in the form of a letter X, which should make the center hair easy to distinguish.

Base. The leveling head is mounted on the turntable or base by means of a center pin on which it can both tip and rotate, and four leveling screws. These screws are threaded into the leveling head and rest on the leveling plate or turntable. They are expanded into knurled wheels for convenience in turning with the fingers, and have expanded feet which do not turn with the screw, and which protect the plate.

The turntable base has internal threads by means of which it can be screwed on

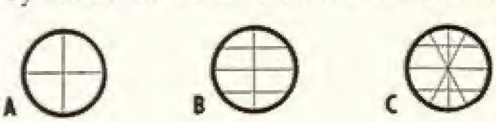


Fig. 2-4. Sighting hairs

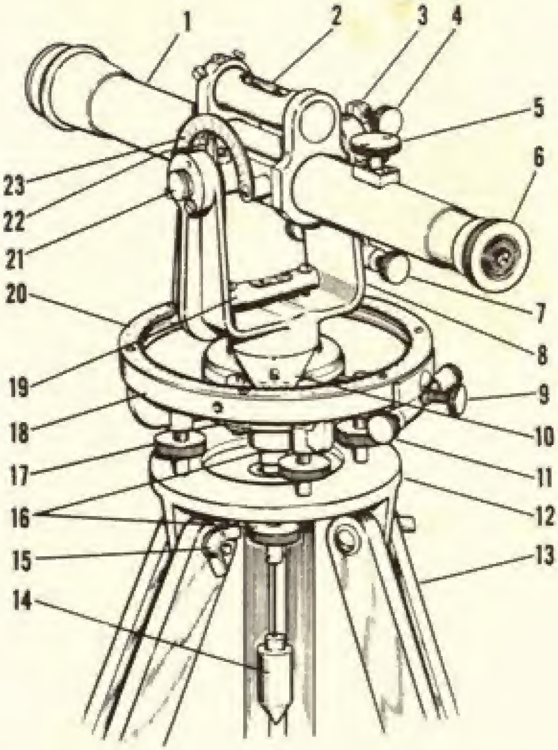
Fig. 2-5. Level transit

to the tripod head. It may have a hook on the bottom, on the axis of revolution of the U frame, from which a plumb bob may be suspended. This part of the base may also be made to slide a limited distance horizontally, relative to the tripod head, for convenience in centering the instrument directly over a mark.

Tripod. The tripod consists of three wooden legs, hinged together by the top piece which is threaded for the instrument. These threads should be protected by a cap when the instrument is not mounted. The legs may be one piece, or two pieces sliding on each other and locked by a screw clamp.

The base may be rested directly on a flat rock or stump, if it is not possible to set up the tripod, but this is not recommended.

Convertible Level. The convertible level is similar except that the telescope is fastened to the frame by clamps that may be readily unfastened, and both the frame and the scope have a spirit level. The telescope may be unclamped and mounted in



1. Telescope
2. Telescope Bubble Assy
3. Vertical Clamp
4. Vertical Clamp Screw
5. Focusing Screw
6. Eyepiece Cap
7. Vertical Tangent Screw
8. Telescope Support
9. Horizontal Clamp Screw
10. Horizontal Circle Vernier Plate
11. Horizontal Tangent Screw
12. Tripod Head and Base Plate
13. Tripod Leg
14. Plumb Bob
15. Tripod Wing Nut
16. Center Screw
17. Leveling Screw
18. Leveling Head
19. Support Level Tube
20. Horizontal Circle Scale
21. Telescope Trunion
22. Vertical Arc Pointer
23. Vertical Arc Scale

Fig. 2-6. Parts of level transit

a socket in which it can rotate vertically, and its vertical angle is shown on a curved scale beside it. When used in this position, the horizontal cross hair indicates the slice of the view which is at the vertical angle indicated by the scale.

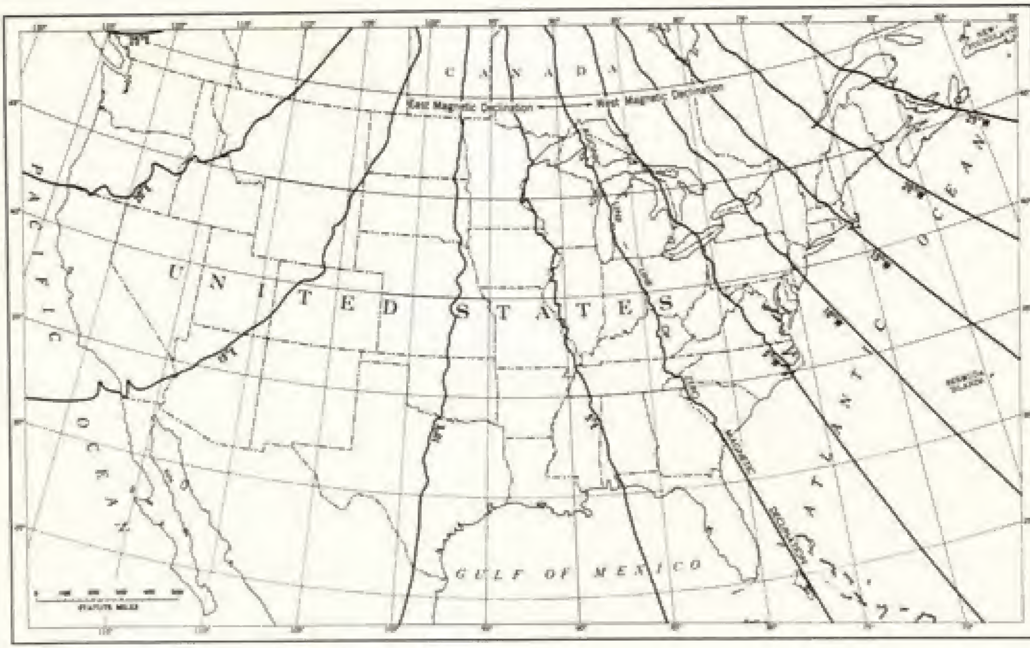
When this instrument is used as a level, it should be checked according to both the frame and the scope levels. Lack of agreement between these may indicate worn or dirty clamps. If they cannot be reconciled, work should be done according to the telescope level, although the best practice is to have the instrument adjusted before using it.

Transit. The level transit, two models of which are shown in Figure 2-5 and 2-6, has a telescope permanently mounted so that it can swivel vertically. When used as a level, the reading on the vertical scale should be zero, and the frame and telescope levels should be in exact agreement.

Compass. Compasses are standard equipment in transits, and can usually be obtained for other type instruments that have a horizontal scale. They are not necessary for the work to be described in this chapter, although it is often convenient to know the general directions of lines.

Surveys are generally based on the true north, from which the compass north varies rather widely. Part of this variation may be obtained approximately from the map, Figure 2-7, or more exactly from local sources. Another source of mistakes is the magnetic attraction of magnets, iron, and iron ore for the compass needle. It is also affected by the time of day. No confidence should be placed in a compass reading taken near machinery or electrical apparatus. Metal objects in the observer's pockets may cause errors.

Setting Up. The first step in using the instrument is to set up the tripod. The top



Courtesy of U. S. Coast and Geodetic Survey

Fig. 2-7. Magnetic declination map

should be as level as possible, and the legs pushed into the ground firmly. On a slope, two legs should be downhill. The protecting cap is removed and the instrument screwed on. The telescope frame should be unlocked so that it is free to rotate. The telescope can then be held in one hand and the base screwed on the tripod with the other.

Leveling. The instrument must now be leveled by means of the four screws. The telescope is turned so that it is over two of them, and those screws adjusted until the bubble in the level is exactly in the center of the scale. The screws are turned at the same time in opposite directions, so that one pushes the leveling head up while the other makes space for it to come down, as it pivots on its center pin.

The bubble moves in the same direction as the left thumb, as indicated in Figure 2-8. If the two screws are turned exactly the same amount, the tension on them will remain constant. If the screw toward which the bubble is moving is turned farther, it will jam both screws. If the screw behind the bubble is turned the most, the tension will be reduced and the screws may lose contact with the turntable.

If both screws are turned to the left (clockwise), or one is turned left while the other is stationary, they will be jammed; while if one or both are turned to the right (counter clockwise) they will both lose contact.

The screws should be kept in light contact with the plate during the adjustment and tightened somewhat as it is finished.

When the bubble is approximately centered, the telescope should be swung ninety degrees so as to be over the other pair of screws, which are used to center the bubble in the same manner. This adjustment will disturb the first one, so the telescope must be swung into its original position and leveled, this time more exactly. It should then be checked in the second position, and adjustment in the two positions made alternately until it does not move during

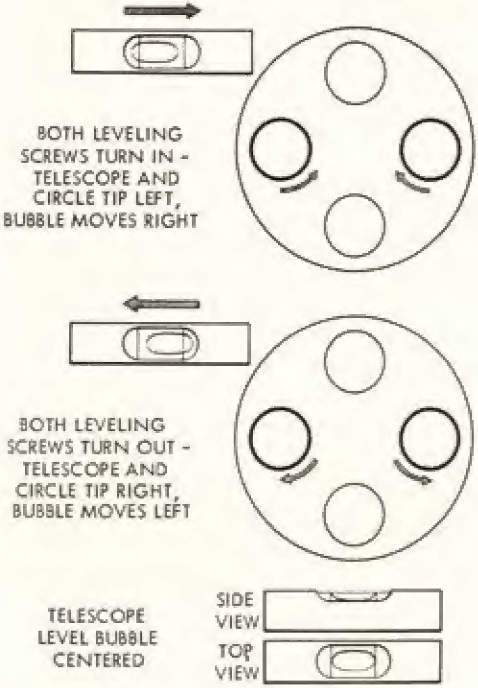


Fig. 2-8. Leveling screw action

the swing through this quarter circle arc.

The telescope should now be swung through the other three quarters of the circle. If the adjusting screws are tight, and the tripod has not been disturbed, the bubble should not move. If it does move, and the table cannot be leveled so that it will not move when swung, the spirit level is probably out of adjustment.

Re-Leveling. During use, the spirit level should be checked occasionally and the instrument re-leveled if necessary. The tripod may settle into the ground, particularly if on some unstable base such as ice, wet clay, or oil road top. Jars from focusing the telescope, or the wind, or other causes, may disturb it. Sometimes it is necessary to put small boards under the legs to avoid settlement.

Leveling Rod. The instrument's companion piece is the leveling or target rod. This is a measuring stick, marked in feet, tenths, and hundredths of feet; or in feet, inches, and eighths of inches. It may be eight to fifteen feet long, and usually is in two or three pieces which slide on each other, or, occasionally, are hinged or pegged together. The sliding type must be fully closed or fully open to be accurate.

Long rods are very desirable in hilly country.

Spaces may be marked by fine lines similar to those on a ruler, in which case it is called a New York rod. A Philadelphia rod uses the division lines as units of measurement in themselves. See Figure 2-9. A rod in the decimal scale has the tenths of feet each divided into ten equal sections, alternating black and white. If inches are shown, each is divided into eight equal bars of alternating color.

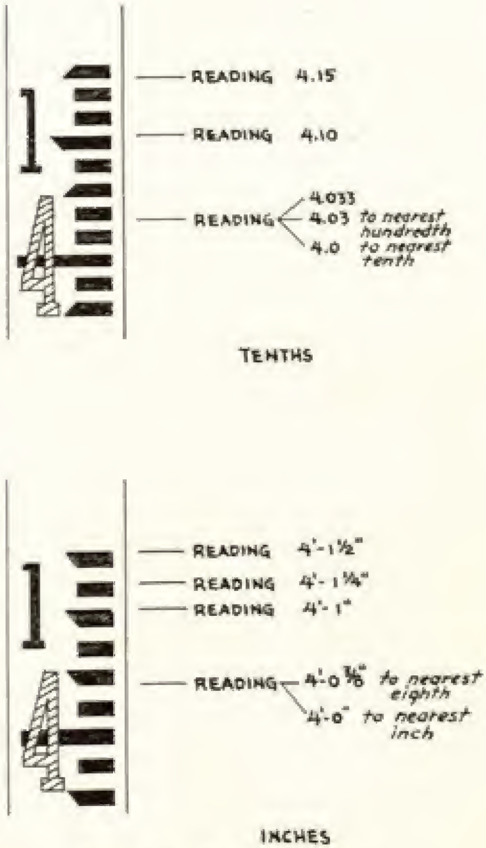


Fig. 2-9. Philadelphia rods

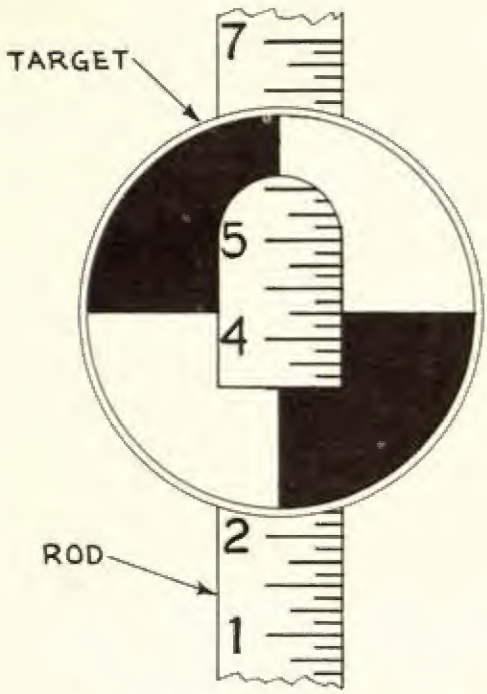


Fig. 2-10. New York rod and target

The target, 2-10, is a metal disc that slides on a track on the sides of the rod. It is painted in quadrants, alternately red and white, with the division lines horizontal and vertical, or in other conspicuous patterns.

The rod man moves the target up and down on the rod in response to signals from the instrument man. Readings can be taken in this way when distance or haze prevents reading figures on the rod.

The target may include a vernier, in which case it can be used for precise work requiring reading of fractions of the smallest divisions of the rod scale.

The rod is used for measuring the distance from the instrument's line of sight down to a point. If the point is almost as high as the instrument, this distance will be short; if it is much lower, the distance will be long.

The elevation of a point is the distance which it is above some standard level. This may be mean sea level—halfway between high and low tide marks—or some local point to which an elevation is assigned arbitrarily.

Elevations are usually positive numbers, measured up from a base point or plane. Rod readings are negative, being measured down from the plane of the instrument.

In taking levels, the positive elevations are obtained from negative rod readings. Care must be taken to avoid confusion. It must be remembered that for any instrument setting, the high readings are low elevations, and vice versa.

USE OF LEVEL

Use of the instrument as a level depends upon the fact that its cross hair indicates a horizontal plane, level with the observer's eye in all directions. By use of the rod, the amount by which a point is lower than this plane can be measured, and the relative elevation of any number of points within range can be calculated from rod readings. Points above the cross hair cannot be measured, except on vertical walls, without moving the instrument higher and resetting it.

Levels are most accurate over short distances. If the instrument must be used when out of adjustment, readings should be taken as nearly as possible at equal distances.

Converting Readings to Elevations. If the instrument is to be set up only once on a job, and no record is to be made of observations, the rod readings can be used to figure heights. However, since these numbers are negative, the beginner will avoid confusion by calling the lowest point—that with the highest rod reading—zero elevation. The other points will then each have an elevation equal to the difference between its reading and that of the zero point.

Another method of converting to positive numbers is to subtract each reading from some number larger than the highest

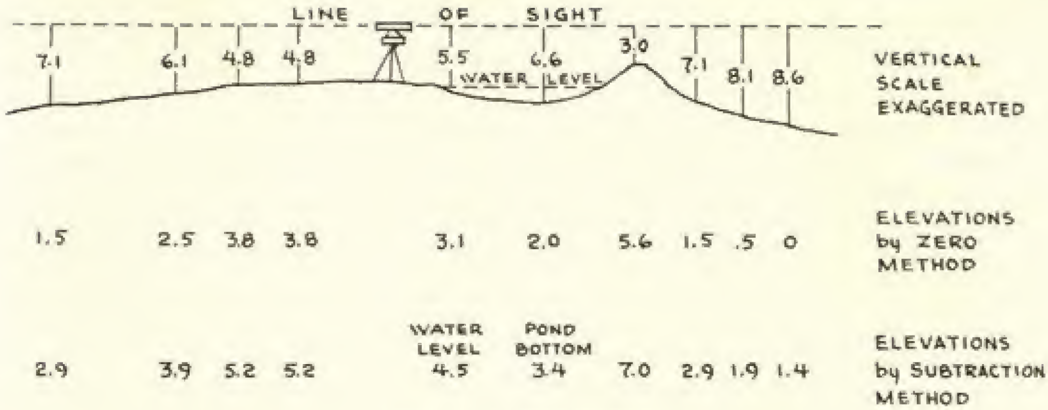


Fig. 2-11. Rod readings

reading. Figure 2-11 shows a series of readings taken to determine in which of two locations a drainage ditch should be dug, with figuring done by both the zero and subtraction (from plus 10) methods.

Bench Marks. If the elevations are to be recorded for future use, it is necessary to have some fixed reference point which will not be disturbed and which can be readily identified. A knob on firm bedrock, a nail projecting from a tree trunk, a mark on a building, or a stake hammered flush with the ground may be used. Such a point is called a benchmark, and is abbreviated as BM. A reading is taken the first time the instrument is used, and again each time it is set up. These readings will probably all be different, but in each case the elevation of the instrument may be found by adding the rod reading to the benchmark elevation.

Since the benchmark is the most permanent point observed, it is good practice to assign an elevation to it, and to calculate all other elevations from that. An assigned number should be large enough so that no elevation less than zero will be found on the job, as working with minus figures may cause confusion and error.

If levels have been taken previously in the area, engineers' benchmarks may be found, in which case it is wise to use them. If possible, the elevation assigned to them in the previous survey should be used to facilitate comparison between the two sets of levels.

Even if engineers' benchmarks cannot be used directly in surveying the job, it may be advantageous to run a level to one, and note its elevation in relation to the contractor's own benchmark, so that the two systems can be compared if necessary.

If the job is a type that will involve frequent checks of levels, as on a road where stakes may be knocked out by machinery, it is a good plan to set up benchmarks so that one will be visible from each point where the instrument will be used. This saves time in taking grades on a few stakes and eliminates common errors in moving the instrument, or in taking an elevation from the wrong line stake, or a stake which has been disturbed.

All benchmarks should be figured very carefully, and re-checked at least once.

Recording Readings. Another requirement in recording observations is to identify the spot at which each reading is taken. This is usually done by taking readings at set intervals, such as ten, or fifty, or one hundred feet. These distances should be marked by stakes, pegs, small rock cairns, or in other ways. The first stake or mark

of the series is called the zero stake, and the others identified by their distances from it. It is customary to give distances in units of hundreds, followed by a plus sign and the other figures of the distance. The zero is written 0 + 0, the fifty foot mark 0 + 50, and the hundred 1 + 0. If any points on the line are needed which are not in the series, the distance is measured and entered in the notes with the reading, as 0 + 35.

Important ground features along the center line, such as crests of rises, bottoms of dips, or beginnings of rock outcrops, should be taken in addition to the stake readings.

Elevations may be taken from the ground, from the top of the stake, or more rarely, from a mark on a stake. If taken from the ground, it should be stamped or cut flat. Such readings are not as accurate as those taken from the top of a stake, and may be very difficult to check back, but they can be used directly in preparing profiles and figuring cut and fill. If the top of the stake is used, it is necessary to measure the stake height.

Tapes. Measuring is usually done with a steel tape, often called a chain by surveyors. Fifty foot and hundred foot lengths are standard, and will suffice for most purposes. They should have a non-rusting finish as it is often difficult to dry and oil them immediately after wet work. Care should be taken not to kink a tape, or to bend it sharply, as such abuse may break it.

If the numbers become illegible, they can be fixed for rough work by measuring and marking the feet, and perhaps some fine divisions, with paint. A broken tape can be repaired by means of a splint and two rivets.

Cloth tapes stretch readily, and are not accurate enough for even rough use. Metallic tapes, composed of cloth with interwoven wires, are variable in quality and resistance to stretching. If used, they should be checked occasionally by a good steel tape.

Steel tapes change length with temperature and stretch under tension, but these changes are so small that they can be ignored in open work.

Tapes must be held level, or very nearly so, on slopes, as engineers' land measurements refer to distances on a horizontal plane. The downhill end of the tape may be placed exactly above the desired point by use of a plumb bob, or by dropping pebbles from the tape end.

Center lines usually include angles or curves. If the former, measurements must be made to and from the angle point, rather than by a shortcut. Gradual curves may be measured in a series of chords (straight lines beginning and ending in the curve). Sharper curves may require a reduction in the length of the chords, as from a hundred to fifty, or twenty-five or even ten feet. The difference in length between the chord and the arc of the curve may be readily found by laying the tape along the curve from one chord point to another; or measuring a distance along it in very short chords, then measuring the distance between the two points directly. If no significant difference is found, the chords are not too long.

Tapes are best suited to two-man use. However, the loop on the zero end can be anchored in dirt with a screwdriver, and to stakes with a pushpin or thumbtack, and measurements made by one man.

Ground measurements may also be made with the rod, with a short rule, a stick of known length, or for very rough work, by pacing.

Stadia. If the instrument is equipped with stadia hairs, it may be used to measure distance as well as elevation. If the stadia ratio is the usual 1 to 100, and the rod is marked in feet, tenths and hundredths of feet, each tenth visible between the stadia hairs indicates a distance of ten feet from the center of the telescope to the

rod. Six tenths would mean a distance of sixty feet, a foot would mean a hundred feet. This distance may be noted at the same time as the cross hair reading.

If the rod is marked in feet, inches, and eighths of inches, each inch indicates a distance of eight and a third feet, each foot a hundred feet.

If a distance is to be measured off, the rod is held at increasing distances from the instrument in response to signals, until the proper number of markings show between the stadia hairs.

If the rod is partially hidden by brush, a reading may be made between the center hair and either stadia hair, and multiplied by two, with only slight loss of accuracy.

The rod should be held perpendicular to the line of sight of the telescope. On level ground, it should be vertical; looking downhill, it should be leaned away from the instrument; and looking uphill, leaned toward it. If it is not at the proper angle the reading will be too small. The correct angle can be found by pivoting it slowly toward and away from the instrument, until the maximum reading is obtained.

Turning Points. If elevations are to be taken for any points above the cross hair, the instrument must be picked up and reset at a higher elevation. It must be located so that it can take a reading on at least one point that was taken from the old setting. This point (turning or transfer point) is preferably one of the higher elevations (low readings) taken, and should lie between the two instrument locations. It is best taken from the top of a firm stake, or a knob or a well marked spot on rock or hard ground, so that the rod set on it will be at exactly the same height at the second reading as at the first. Accuracy in reading at the turning point is very important as any error made will persist through the rest of the survey. Amateurs are advised to use two turning points with each move, as mistakes in reading or in arithmetic should then show up immediately.

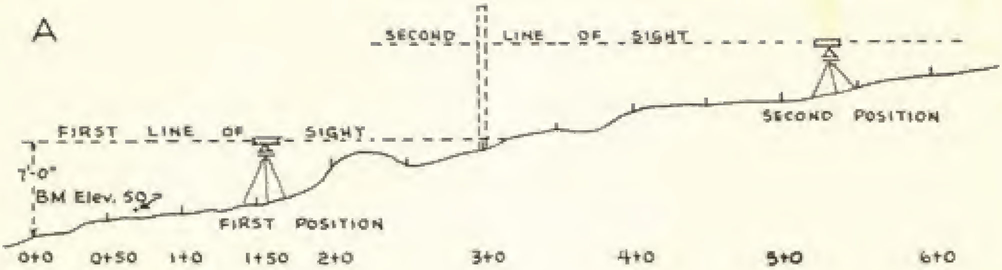
The new instrument elevation (abbreviated H.I. for Height of Instrument) is found by subtracting the smaller reading from the larger one for each turning point, and, in an uphill move, adding the result to the first elevation of the instrument.

Recording and Figuring. Figure 2-12 shows some of this work. (A) shows the slope, the location of benchmarks and stakes, and the two instrument positions used. (B) is an informal set of notes of rod readings and calculated elevations. (C) is a profile drawn on cross section paper from the notes in (B). It is made by drawing a base line, assigning it an elevation lower than those of the stakes, and making each square represent a certain distance. In this diagram, each square represents one foot vertically and ten feet horizontally. This vertical exaggeration is necessary to have a large enough scale without making the drawing impossibly long.

The profile is useful in giving a picture of the slope, in determining gradients of roads or ditches, and in figuring the cut and fill necessary to convert the present grade to the new one.

The dotted line is the subgrade for a proposed road. It will be seen that the depth of cut or fill on this line may be approximately determined by measurement with a ruler; the elevation of any point on the road, in relation to the benchmark, can be found in the same manner.

Moving Downhill. If, at the original or at any later location of the instrument, points to be taken are so low that the rod is below the cross hair, the instrument must be moved downhill. A turning point (or points) is chosen with the lowest possible elevation (highest reading), the instrument moved, and new readings taken. The low reading is subtracted from the high one and the result subtracted from the earlier instrument elevation.



B

	STATION	ROD on GROUND	ELEV.
FIRST POSITION	BM #1	5.80	50.0
55.80	0+0	7.0	48.8
	+50	6.1	49.7
	1+0	5.8	50.0
	+50	5.0	50.8
	2+0	2.8	53.0
	+20	2.0	53.8
	+50	2.6	53.2
	3+0	1.2	54.6
SECOND POSITION	3+0	8.2	
62.8	+50	6.8	56.0
	+75	7.4	55.4

BM #1	50.0 Elev.
ROD FIRST POSITION	5.8
INSTRUMENT HEIGHT (H.I.)	55.8
TRANSFER 8.2 - 1.2	7.0
H.I. SECOND POSITION	62.8

GROUND SURFACE
ROAD SUBGRADE

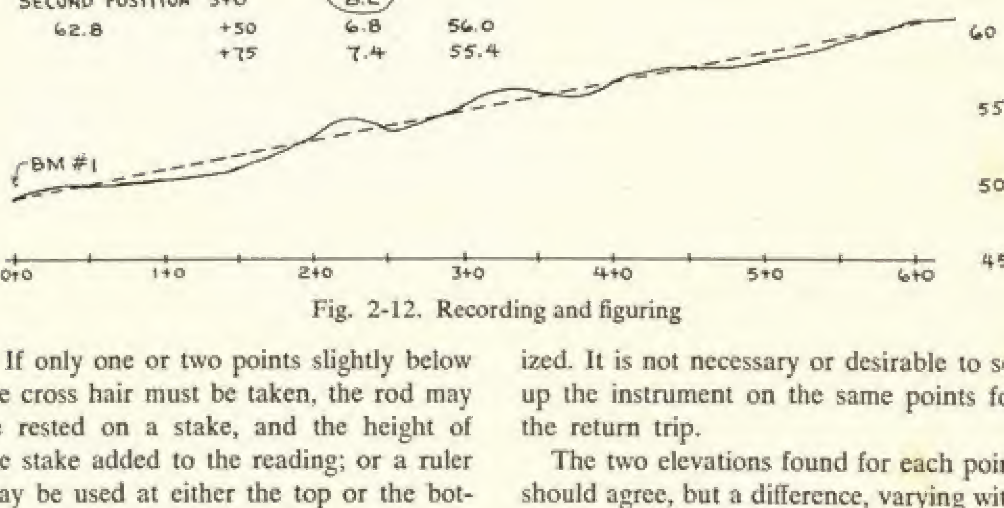


Fig. 2-12. Recording and figuring

If only one or two points slightly below the cross hair must be taken, the rod may be rested on a stake, and the height of the stake added to the reading; or a ruler may be used at either the top or the bottom of the rod to extend it.

Check Runs. When all the necessary points have been taken, the accuracy of the work may be checked by taking levels back to the starting point. This is usually a faster operation than the outward trip, as it is only necessary to take transfer points and benchmarks. If frequent benchmarks have not been placed, it is advisable to use the same turning points, or to take readings on a few of the grade points, so that if an error is present, it may be localized. It is not necessary or desirable to set up the instrument on the same points for the return trip.

The two elevations found for each point should agree, but a difference, varying with the care with which the work is done, generally exists. Benchmark runs should be held to within a few hundredths of a foot, even in rough work where a difference of several inches on a grade point might be allowable. If any considerable amount of cut or fill is needed, even benchmarks may be left as approximations, until skill or time is available for a more careful run. Any discrepancies found in the check run should be listed in the notes.

If benchmarks are set at the beginning

and end of a run, and check properly on the return trip, it will not be necessary to back check any later run on which these two elevations show correctly. However, if benchmarks have been set by other parties in some previous survey, they should be checked the first time they are used, as they may be wrong or their description misunderstood.

ROADS

Reference Stakes. A large part of a contractor's instrument work is likely to be concerned with roads. Except for driveways and some pioneer and farm roads, most of them are built to specifications which must be followed rather closely. The nature of roadbuilding, however, is such that stakes are extremely short-lived and must be frequently replaced or checked.

Locations of stakes should be recorded in relation to a baseline, but side stakes, or measurements between trees or walls, provide a more convenient reference. Very often the surveyors set only one line of stakes, as along the center line, or at an offset (distance to one side of the center line), which should be noted on each stake. The station number, and usually the amount of cut or fill required, are also written on the stake.

The contractor will usually set additional stakes himself to locate road edges, outer limits of cut or fill, or other parts of the work. These are set by measuring the rquired distance from the surveyors' stake, at approximately right angles to the center line of the road. The contractor sets road edge stakes six inches outside of the line to allow machinery to work to the edge of the subgrade without necessarily disturbing the stakes. At the same time guide stakes may be set farther out from the center line, at a distance which will put them outside the working area. They are best set on both sides so that any of the working stakes may be replaced by simply measuring between the guides.

Where trees or heavy rocks are near the road, nails may be driven into trees, or marks chiseled on rocks, on opposite sides of the road, and a tape stretched between them, and the reading at the center line and the ends noted. The station where the tape crosses center is also noted. Access to these notes will make it possible to find the center quickly and accurately again.

When a few center line points can be found from side references, it is often possible to sight in the rest of the missing stakes by eye with reasonable accuracy.

Grade Stakes. Taking of road levels involves at least three lines—center and two road or gutter edges. In addition, frequent cross sections must be taken when the land slopes across the right of way, to determine the extent and volume of cuts and fills. On steep slopes, cutting back a bank may involve much more excavation than digging for the road itself.

Engineers' grades usually consist of a series of elevations for the finished road. These are plotted on the same sheet of cross section paper as the profile of the ground surface, and the depth of cut or fill determined by measuring the distance between the two lines. These figures, if used directly, will not be accurate for most subgrade work, as the thickness of the pavement or gravel and of any special subgrade material must be subtracted to obtain the rough grade elevations.

A misunderstanding as to whether figures on grade stakes are for finish grade or subgrade can be very expensive. Use of subgrade figures for preparing subgrades is usually most satisfactory.

The contractor may obtain from the engineer a list or profile showing subgrade elevation at each station, and information as to the location and elevation of benchmarks. This, combined with sufficient field references to show the center line, will

Ground Surface AD Level
Cut at ℄ JL 4'-0" given
" " gutter BG 6'-0" "
GK & KH are simplified subgrade lines
JK, BE & CF – each 3.3' scaled
BC = EK + KF = 35'-0" given
AB = CD = 12'-0" scaled
EG = FH = 2.7' scaled

Road & Gutter Cut = ▭BEFC + ΔEGK + ΔKFH
Area ▭BEFC = BE × BC = 3.3 × 35 = 115.50'
Area $\Delta EGK = \Delta KFH = \frac{EG \times EK}{2} = \frac{2.7 \times 17.5}{2} = \frac{47.25}{2}$
Area $\Delta EGK + \Delta KFH = 2 \times \frac{47.25}{2} =$ 47.25
9 ⌊162.75
Area road cut cross section (sq.yds.) = 18.08
Area side cut = ΔABG + ΔCHD
" $\Delta ABG = \frac{AB \times BG}{2} = \frac{12 \times 6}{2} = \frac{72}{2} = 36$
" $\Delta CHD = \frac{CD \times CH}{2} = \frac{12 \times 6}{2} = \frac{72}{2} = 36$
Area slope sections (sq.yds.) 9⌊72 8.00
Total cut area (sq.yds.) 26.08

Fig. 2-13. Figuring a cross section

enable him to replace stakes which have been knocked out, and to find the depth of cut or fill required, by comparing the ground elevation with that required for the road.

Cross Sections. Cross sections provide data to figure the cut and fill for the road, gutters, and side slopes.

Figure 2-13 shows a sample cross section with the arithmetic involved in computing its area. The road and gutter surface have been simplified in the calculation, as this reduces the work without introducing too large an error for rough figuring. The problem is also simplified by a horizontal ground surface.

The cut is divided into slope triangles; and a road section, which in turn is divided by the line EF into a rectangle and two triangles. The data given by the engineer is labeled "given," and that measured off the diagram as "scaled." The areas of the triangles and the rectangle are readily computed, their measurements in feet being used for convenience and the result converted into square yards by dividing by nine.

The areas of a succession of cross sections are obtained in this manner and averaged by adding together and dividing by the number of sections added. The result is multiplied by the length in yards of the area in which the sections were taken, giving the number of cubic yards of excavation required.

Where the ground slopes irregularly the ground surface is simplified by drawing straight lines, and the cut and fill areas are divided into triangles.

The road and gutter cuts could be figured by averaging the width and average depth at each cross section, then multiplying their product by the length of the sectioned area. The slope sections cannot be averaged as their areas vary with the square of the depth of cut, and use of average depth would indicate a much smaller yardage than that actually required.

This subject is discussed further in Chapter 8.

LOCATIONS

Turning Angles. When an instrument is used to turn angles—that is, to measure the horizontal angle between two lines or directions—the axis of revolution of the telescope must be exactly above the intersection of the lines, which may be marked

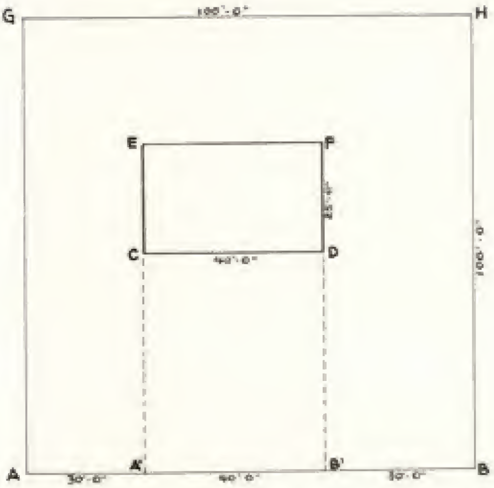


Fig. 2-14. Locating house site

by a nail in a stake driven flush with the ground, a cross chiseled in rock, or by markings on concrete or metal plugs.

When the instrument is set up over a point, a plumb bob should be hung at its center of rotation from a hook or through a hole usually provided. The point of the plumb bob should be just above the mark, and an amateur may have to move the tripod repeatedly before it is placed right.

If the instrument has a shifting base so that it can slide on the tripod, setting up over a point is greatly simplified.

A range pole is a convenient accessory in line and angle work. It is a pole seven or eight feet long, equipped with a metal point. It is painted alternately red and white in bands one foot wide. It is lighter than a rod and because of its conspicuous pattern is more readily seen at a distance.

This pole is set on one of the lines in question. The instrument is swung so that the vertical cross hair is on the pole. The rotation is locked, and the hair lined exactly on the pole by turning the horizontal tangent screw.

The reading on the horizontal circle and on the vernier is recorded.

The pole is placed on the other line and sighted in the same way. The difference

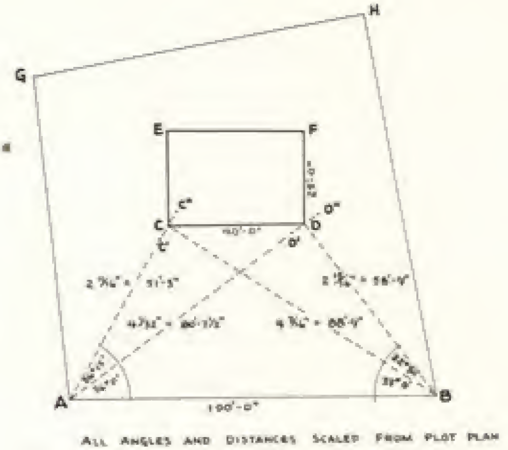


Fig. 2-15. Locating house site in irregular plot

between the two readings is the angle between the lines.

Line and angle work may be done to stake out on the ground locations described on a blueprint or map; or to make a record of ground features or locations on paper so that they may be used in figuring, or replaced or relocated if necessary.

Staking out is best left to engineers if possible, as accurate work involves trigonometry and skillful use of the instrument, and inaccurate work may result in very expensive mistakes. However, in emergency, or when results need be only approximate, the contractor can do it himself.

Staking from a Map. An example of staking out from a map is shown in Figure 2-14. A building, 25′ x 40′, is to be erected at the location shown on a plot 100′ square. Lot corner stakes are at A and B.

The instrument is set up on A and sighted at B. The distances AA′ and A′B′ are measured along the line of sight, and stakes driven at A′ and B′. The instrument is then set up on A′, sighted on B, and turned 90°. The distances A′C and CE are measured and stakes put at C and E.

The transit is now set on C, sighted at A′, and turned 90°. the distance CD measured, and a stake placed at D. F is located from the instrument set at E in the same manner. The instrument is now set on F, sighted at E, and turned 90°, measuring the

distance to D and B′ for a check on the accuracy of the work. The amount of error allowable will depend on job requirement.

This technique is practical for the amateur only on square or rectangular lots. Another method that is applicable to any lot for which two widely spaced locations may be found both on the map and in the lot, is illustrated in Figure 2-15. The house is located on the plot plan and lines drawn from the known corners A and B to the near corners of the building, as shown. These lines are measured and converted to feet according to the scale, and the angles they make with the line AB and with each other are measured with a protractor. Figures are written on the plan.

The instrument is set up on A and a bearing taken on B. A 36° angle is turned, the line AD measured, and the stake D placed. An additional angle of 26° 15′ is turned, AC measured, and C marked.

The instrument is now set up at B, sighted on A, turned 32°, and BC measured. The end of this line should be the stake previously driven at C, but if it is not, a second stake C is placed. The instrument is turned an additional 22° 30′, and BD measured in the same manner. If the same locations are found for C and D from both A and B, and the line CD is the required length, the work thus far is correct. If serious disagreement is found, the work must be rechecked.

The instrument may next be set at C, sighted on D, and turned 90° left. The distance CE is measured and stake E driven. F is located by setting the instrument at D in the same manner. This part of the work may be checked by setting up on E, sighting C, turning 90°, and measuring EF.

The accuracy of the location of the house in the lot will depend on exactness of the measurement on the map, and the ability to read horizontal angles correctly. Amateurs may be off several feet in such work, and should do it themselves only when such differences are allowable. Under any circumstances, it is necessary to get the building walls of proper length and at the proper angles to each other.

The stakes A and B may be used as benchmarks, and elevations taken at the same time as the bearings and directions.

Recording. If the location of existing stakes is to be recorded so that they can be replaced if destroyed, the work is the same except that the angles are obtained by sighting the instrument and copied from the horizontal circle onto a sketch. Distances are measured in the field and noted on the sketch, which is most conveniently made on cross section paper, roughly to scale. This sketch is used in the same manner as the map in the previous discussion in replacing the stakes. Results are generally much better as the field figures are more accurate than those obtained with ruler and protractor from the map.

If field observations are to be entered on a map, the baseline or points should be related to features shown on the map, as corner stakes, points measured on a line between diagonal corners, or measured along a boundary. When the baseline is correctly drawn, angles and distances can be marked in with protractor and ruler.

Without Instruments. Simple location work can also be done without instruments. Figure 2-16 shows the same square building plot. Lines are drawn on the print or tracing prolonging each side of the house to the plot boundaries, from where the distance to the corners is measured. These distances are then measured off on the ground and stakes set.

The distances of the house corners from the boundary lines may be scaled from the map and measured on the ground in directions found by sighting between pairs of boundary stakes.

Sighting may be done by placing a thin straight stake, as at L and another at Q.

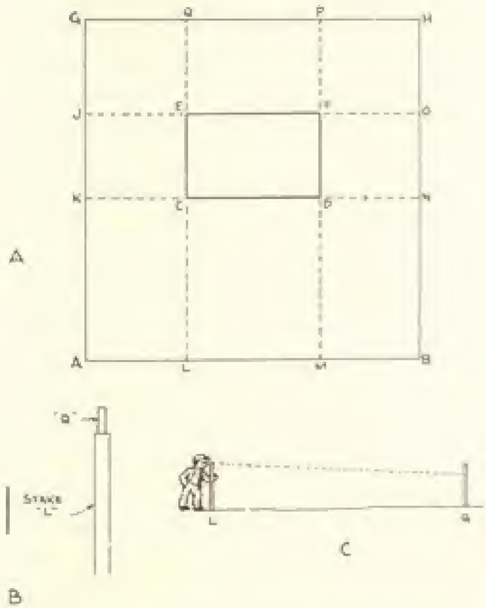


Fig. 2-16. Staking without instruments

A man may stand behind the stake at L in such a position that, when he looks with one eye, the stake at Q is centered on L and just above it, as in Figure (B). Another man, carrying a third stake, measures the distance QE, keeping on the line LQ in response to directions from the observer. The measuring is best done by pinning the tape to Q. The stake is set at E so as to be directly in line between stakes L and Q. The distance EC is then measured and stake C set in the same way. CL is measured for a check.

Stakes F and D may be placed according to sighting from M to P, and measurements similar to the method used for E and C. The four corners of the building are thus located, and in a regular plot such as this no more work would be needed.

However, as a precaution against error, or in an irregular plot, or one with poorly defined boundaries, it is wise to prolong the other sides of the house into the lines JO and KN, and to sight and measure the corners again from J and K.

Reference Stakes. If the corner stakes have been set for a building in a plot without definite boundaries, and the contractor wishes to be able to reset them if necessary, there are several ways in which markers can be set without instruments.

In Figure 2-17 the house wall lines are shown continued in straight lines out of the digging area. These lines may be established by putting sighting poles on the corner stakes and finding a distant position from which two of these are in line—that is, one partly or completely hides the other. This sighting should be done with one eye and a pole held vertically in line with them. A stake is driven to mark the position of this third pole. The distance from this to the nearest corner stake is measured. This process is repeated for each pair of stakes at the foundation. In the figure, the reference stakes are indicated by Xs and the sight lines by dotted lines. A sketch should be made showing distances.

Any missing stake may be found by sighting from one marker to the other one on the same sight line, and measuring from the nearest marker. Even if the sketch is not available, the point may be found by the intersection of two lines of sight, as described under instrument work.

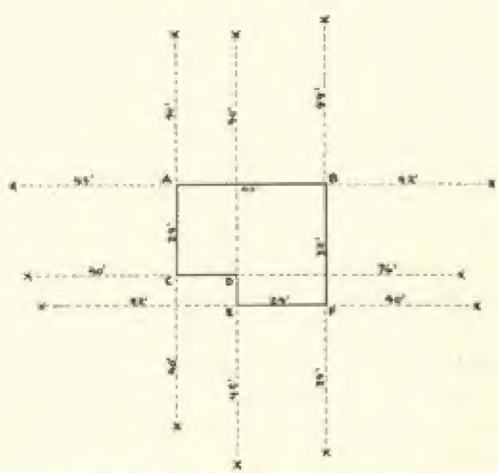


Fig. 2-17. Cross reference stakes

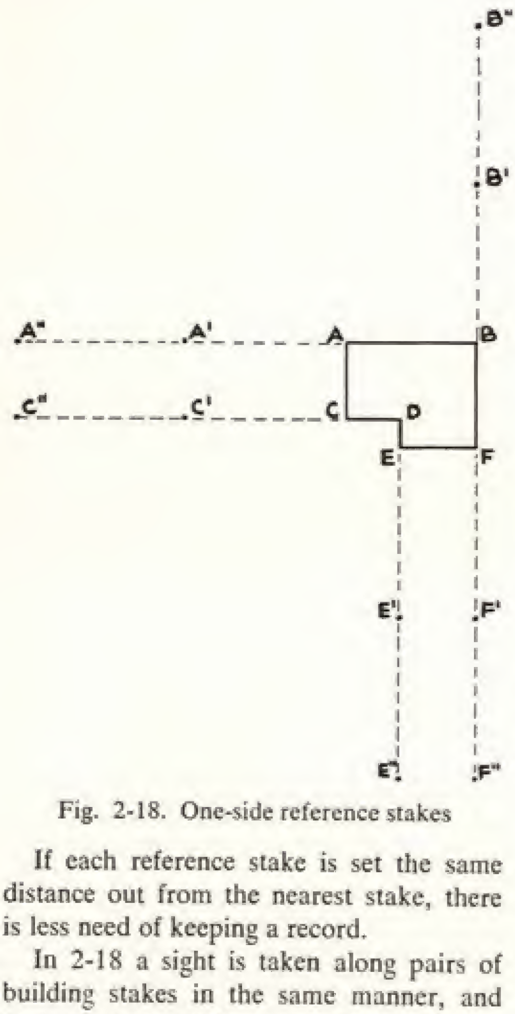


Fig. 2-18. One-side reference stakes

If each reference stake is set the same distance out from the nearest stake, there is less need of keeping a record.

In 2-18 a sight is taken along pairs of building stakes in the same manner, and two reference stakes set on one side, so that the distance from the building stake to the first marker is the same as that between the two markers. The stakes may be replaced by sighting and measuring from the pairs of markers. This method is not as accurate as the other, but it may be used alone or in combination with the first system when obstacles prevent running a line straight across the area.

Instruments give more accurate results than plain sighting, and should be used when available.

Locating a Pond. If an irregular shape, such as a pond, is to be roughly measured and drawn into an existing map, a base line is first established and two points measured off. A number of pegs are driven into the shores of the pond at points which will serve to indicate its outline, and numbered in rotation, as in Figure 2-19. An instrument with stadia hairs is set up at A, a sight taken on B, or on a more distant marker along the baseline. A sight may also be taken on a corner of the house for a check. Sights are taken on all the stakes in rotation, starting at one, the angle read for each one, and the stadia distance recorded. This information is sufficient to locate the pond by drawing the baseline on the map, and plotting distances and angles. However, to avoid the possibility of gross error, it is safer to set up at B, take a bearing on A, and record the angle and distance of some or all of the points observed from A.

The area of a pond so plotted can be easily obtained by counting squares on cross section paper, or by the use of a planimeter, which is a small instrument used for measuring areas on paper.

Grids. If it is necessary to map an area, locating buildings, drainageways, trees, or other features, or to take elevations over a large area in order to prepare grading or drainage plans, a grid should be laid out. This consists of pegs or stakes at set intervals. They should be in straight lines, crossing each other at right angles. These lines, intersecting at the pegs, generally divide the area into squares. The interval may be five to twenty feet or more.

The grid may be laid out in a number of ways. A baseline should be laid out along an edge of the area. The instrument, preferably a transit, is set up at a corner of the proposed grid and sighted along the baseline. Pegs are set every ten feet, or at any other desired interval, measured from the instrument, to the end of the grid. Tape measurement is preferable.

The instrument is now turned ninety

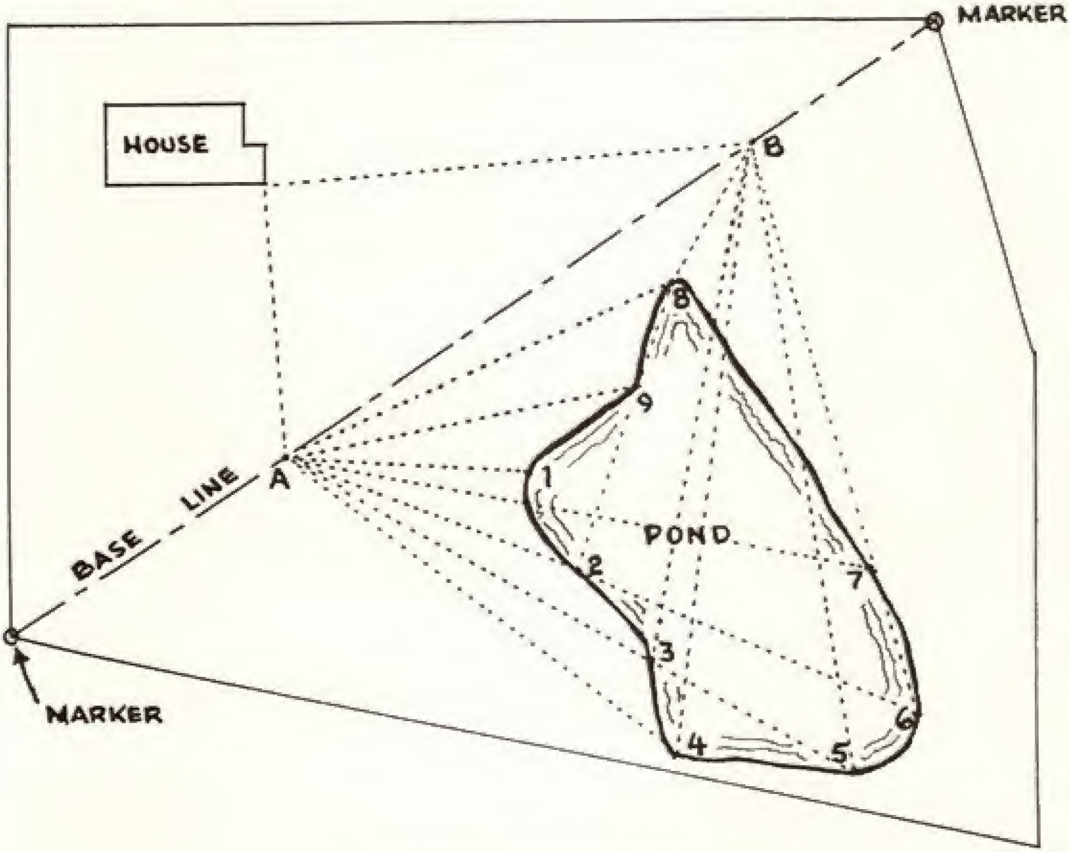


Fig. 2-19. Locating by stadia

degrees, and pegs set at the same interval along the line of sight to the end of the grid. The instrument is set up at the end, a backsight taken, and a ninety degree turn made. Pegs are set at the same intervals along this third line.

The interior pegs may be placed by the use of a long tape from opposite pegs, or the instrument may be set up over each peg in either the first or third lines, sighted at the corresponding peg in the other line, and pegs set according to its vertical hair and measurement.

Obstacles may make it impossible to set all the pegs by any of these systems. Usually, if as many pegs as possible are placed the rest can be filled in by sighting along lines of pegs, with reasonable accuracy.

The grid should now be copied on cross section paper with a point representing each peg. Any landscape features may be readily sketched in by estimating or measuring the distance from the nearest peg, and noting the place of the peg in the grid.

Elevations are now taken on each peg, preferably doing them a complete line at a time to avoid confusion. The rod reading may be written just above each point. Readings should also be taken on high and low spots, drain channels, and anything else of interest, and noted in the correct place on the paper.

When the instrument work is finished, the readings are preferably converted to

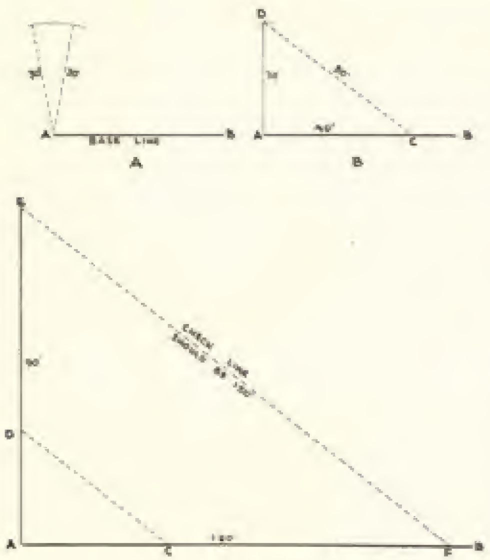


Fig. 2-20. Right angles

positive numbers that can be penciled below the points, and the rod reading crossed out.

This grid sheet can be used for reference for any locations or grading estimates which may be required, and in drawing contours, profiles, and cross sections.

Grids Without Instruments. If no instrument that will turn angles is available, a grid may be laid out with a tape, and elevations taken with a hand level. A baseline is decided upon and a tall stake set at each end. A tape, the longer the better, is pinned at one end and extended toward the other, and lined up by sighting across it from one stake to another. The intervals are measured and the tape moved on and lined up again.

The right angle may be laid out by referring back to the ancient engineering knowledge that if the sides of a triangle are in the proportion of 3 to 4 to 5, the angle between 3 and 4 is a right angle. The process is illustrated in Figure 2-20.

First the baseline is laid out, measured off, and pegs set. The tape is pinned at A, one end of the baseline, and thirty feet measured off at approximately a right angle. The tape is moved back and forth in an arc that is marked on the ground.

The tape is then pinned to the baseline at C, forty feet from the end, and an arc of fifty feet radius described, crossing the first arc. A stake is driven at the point where these arcs intersect. The line AE may be located by sighting along stakes A and D, and will be perpendicular to AB.

These figures have been given for the use of a fifty foot tape, but any measurements may be used as long as the 3-4-5 relationship is preserved. Larger triangles will give greater accuracy. If the grid is large in proportion to the triangle, a diagonal should be measured from E to a point on the baseline either ¾ or 1⅓ as far from A as the distance AE, and any necessary correction made if the diagonal is not in the proper proportion.

A very rough grid may be made by sighting along the sides of a building to obtain the right angles, and spotting in the pegs by eye and measurement.

Obstructions. Buildings, vegetation, and rough ground interfere seriously with primitive instrument techniques and make it more economical to hire an engineer.

Large permanent obstructions require layout of additional lines and angles to work around them.

Brush clearing for sight lines is laborious and sometimes quite destructive. It is handled by setting up the instrument, pointing it in the desired direction, and directing the cutters so that their work will be kept close to the line of sight.

In heavy undergrowth a mistake in turning an angle may waste hours of cutting work.

INSTRUMENT ADJUSTMENTS

Surveying instruments are delicate and are easily put out of adjustment by failure of parts, careless handling, or accidents. It is often not possible to have them checked

or repaired locally; the return to the factory may mean loss of use for weeks or months.

It is therefore desirable that a person using an instrument be familiar with some adjustments that can be made in the field, without special skill. These include setting of telescope spirit level, and the horizontal and vertical cross hairs.

If these are properly set, and the instrument is inaccurate, shop service is probably necessary.

Spirit Level. The telescope spirit level is usually fastened by a pair of vertical bolts. A single nut holds it in a fixed position at one end, and a pair of nuts, one above and one below, permit moving it up and down on the other.

These nuts are usually round and are turned by a special pin, a small nail, or the smooth end of a drill, inserted in radial holes.

Both nuts are turned down, or clockwise, to move the bubble away from the adjusting bolt, and counter clockwise to bring it closer. They must first be unlocked by turning one away from the other, and should be locked again as soon as adjustment is made.

This level can be checked each time the instrument is set up. When the turntable is level, the telescope should be able to swing in a full circle without changing the position of the bubble. If no turntable screw adjustment will permit this, the level is presumed to be at fault.

To adjust, the turntable is leveled as accurately as possible and the bubble centered. The telescope is swung a half circle, causing the bubble to shift. The bubble is brought one quarter of the way back to center by the adjusting nuts, and the rest of the way by using the turntable leveling screws.

The telescope is then swung to its original position, the bubble moved one quarter way to center by adjustment, and centered by the leveling screws. This process is repeated until swinging the telescope does not affect the bubble.

Cross Hair. If the horizontal cross hair is not exactly centered, all readings on the rod will be too high or too low. Readings taken at about equal distances will agree. Greatest errors will be found on long sights.

A reasonably accurate check and adjustment of this hair can be made with the help of a still pond. Two stakes are driven flush with the water surface, about a hundred feet apart. The instrument is set in line with them, ten feet beyond one.

A rod is set on the near stake and a reading taken. This is assumed to be accurate, because the distance is too short for a perceptible error. The target is locked to the rod at this reading, or a note made of it.

The rod is set on the far stake. If the hair is correctly adjusted, the reading should be the same. If it is not, the hair should be raised or lowered until it agrees.

This is done by turning set screws at the top and bottom of the frame which holds the hair. The screws are unlocked by twisting one or the other a quarter or half turn, after which both are turned in the same direction.

Loosening the bottom and tightening the top moves the cross hair down, and turning them oppositely raises it. When the adjustment is finished, they are locked by turning gently against each other. Another reading should be taken to make sure that this does not disturb the adjustment.

The mechanism is fragile and may be damaged by forceful turning of the screws.

The side screws should not be turned during this adjustment.

Small errors are usually present in this method as it is hard to get the stake tops exactly at water level, and if the pond is overflowing, it will slope downward from inlet to outlet. Wind will raise the water against the bank toward which it blows.

If no pond is available, or a more accurate adjustment is required, two stakes

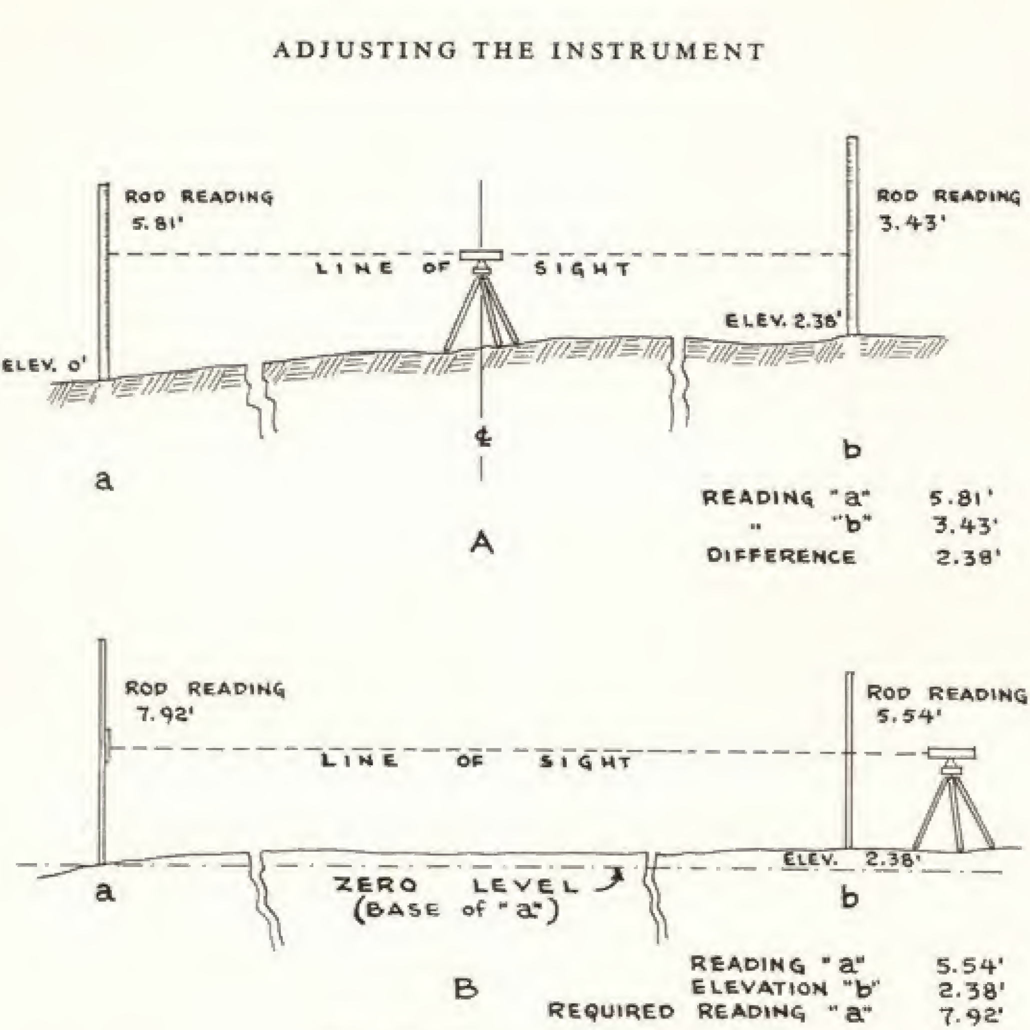


Fig. 2-21. Checking the cross hair

should be driven firmly into the ground, two to four hundred feet apart, and at almost the same level. The instrument is set up halfway between them as in Figure 2-21 (A), and leveled carefully.

A leveling rod is held on each of the outer stakes, and an exact reading taken according to the cross hair. These readings will be accurate with reference to each other, as any error in cross hair height is cancelled out in observations taken at equal distance.

The stake standing on lower ground is assigned an elevation of zero, and has the higher rod reading. The elevation of stake (b) is the difference between the two readings.

The instrument is now set up in line with the two stakes as in (B), about ten feet beyond stake (b). A reading is taken of (b). Then a reading is taken at (a), which should equal the elevation of stake (b) plus the reading there.

If it does not, adjustment is made in the manner described above.

Vertical Hair. The vertical cross or direction hair may be checked by driving three stakes exactly in line at two hundred foot intervals. The line may be determined by sighting with the vertical hair, and the distances measured by stadia or tape. The stakes should be about on the same level.

The instrument is set up over the center stake, leveled carefully, and turned so that

the hair lines up with a rod or pole held vertically over one of the end stakes. The instrument is turned exactly 180°, or, if it is a transit, flipped over vertically. The hair should now line up with a vertical stick on the other stake.

If it does not, the cross hair should be moved one quarter of the way toward the stick by means of adjustment screws on the sides of the cross hair frame. These work in the same manner as the upper and lower screws.

After the one quarter adjustment, the telescope is turned until hair and stick coincide. A 180° angle is again measured off and the rod on the first stake sighted. The hair is adjusted to move toward it one quarter of any distance, then centered on it by moving the scope.

Additional half circle turns, and adjustments, are made until the hair will coincide with both sticks, 180° apart.

MINOR INSTRUMENTS

Hand Level. Rough levels may also be run with hand levels, such as the one shown in Figure 2-22. This consists of a sighting tube, in the top of which is a small spirit level parallel with the line of sight. A slanted mirror reflects the spirit level so that it is seen vertically beside the field of view. The object glass is marked with a center line, and may have two or more stadia lines.

This level is used by holding it to one eye, and tipping it up or down until the bubble is centered at the center line on the glass. Any object cut by this line is then on a level with the observer's eye, and nearby elevations may be determined and levels run in the same manner as with an instrument.

Results are much less accurate, but in rough work this may be more than compensated by the ease of use.

The eye height of the observer may be used as a unit of measurement. In taking

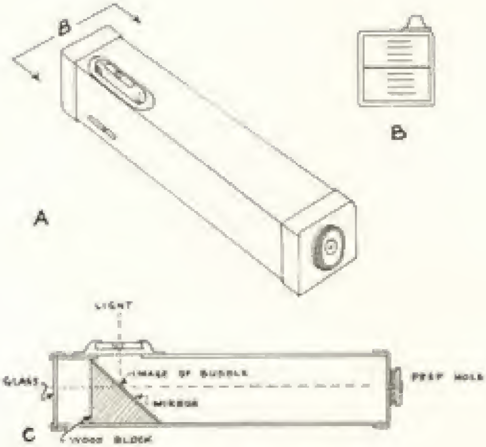


Fig. 2-22. Hand level

the height of a hill, as in Figure 2-23, the observer holds the level to his eye, while the rod man moves up or down the hill in response to instructions, until the bottom of the rod, a stick, or the man's shoe rests on the ground at eye level. The spot is marked, the observer moves to it, standing with his heel on it, and the rod man moves uphill, repeating the process. When the top is reached, the last observation should be taken on the rod, or a ruler or tape, to show the distance from the hilltop up to eye level. The height of the hill is the height of the observer, multiplied by the number of observations, less the rod reading on the last observation.

In working downhill, (B) a target fastened at the top of the rod, or a mark on a long stick, is sighted and moved until it is level with the eye. The observer then moves to that spot, while the target is moved downhill until level with the new position. On the last sight, the distance from the ground to eye level is measured.

Each observation covers a drop equal to the height of the target minus the height of the observer, and will all be equal except the last one, which should be separately figured and added to the others.

An individual's eye height measured from the heel when he is in erect position,

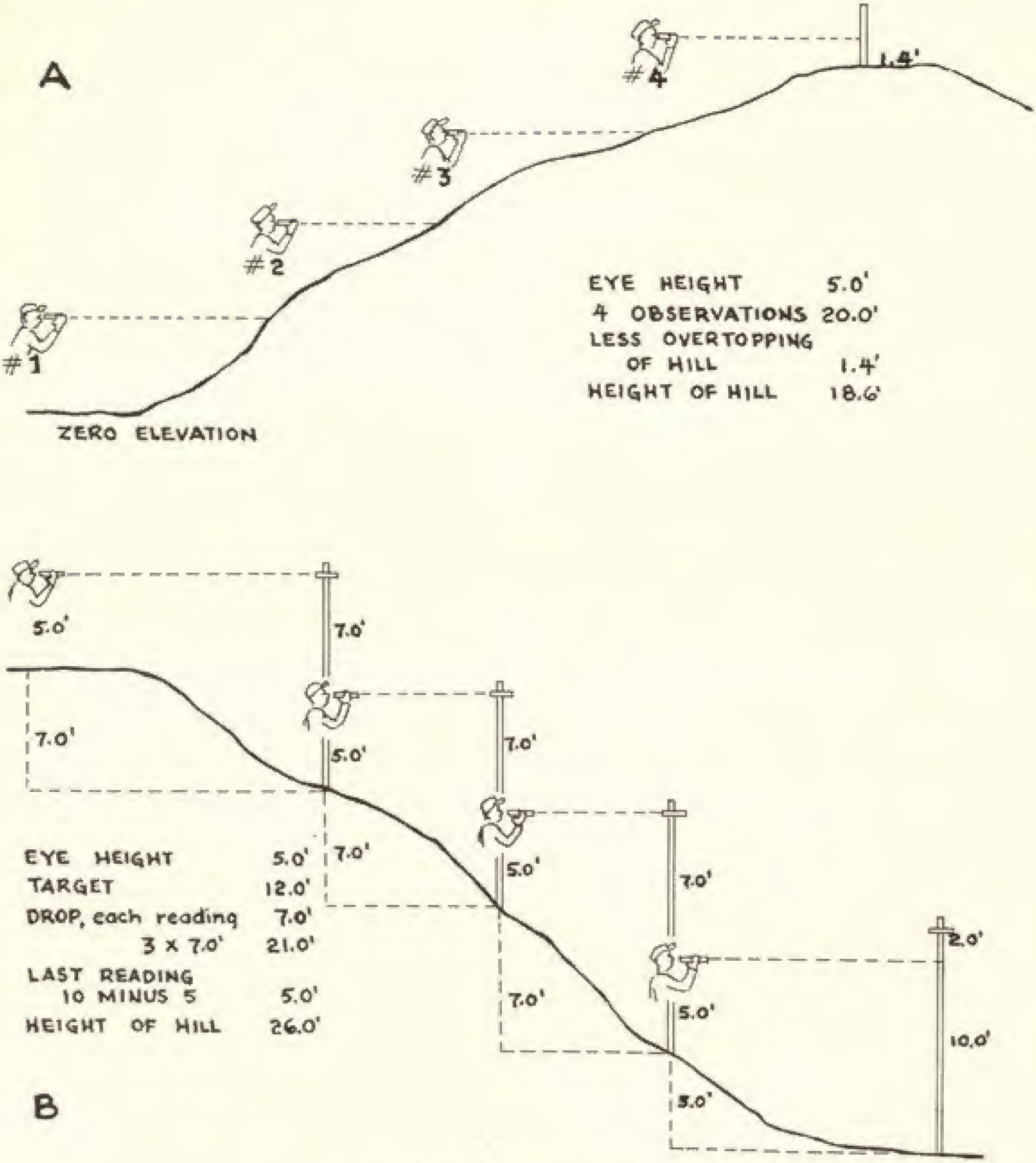


Fig. 2-23. Using a hand level

will seldom vary more than an inch, which is not too large an error for rough work. Care should be taken that the heel, and not the ball of the foot, is placed on the mark.

Level-Clinometer. The clinometer is a special type of hand level which can be used to measure slopes and vertical angles. The spirit level is hinged so that it can be rotated about 45° in either direction, and a pointer and scale indicate the angle between the spirit level and the line of sight. The bubble will appear at the center line of the object glass when the hand level is held at the angle indicated by the scale. The scale is usually graduated to indicate both angles and slopes.

The angle of a slope may be measured

by setting a target at eye height at one end and sighting it from the other. With the center line on the target, the spirit level may be adjusted until the bubble is beside the line. The pointer on the scale will then indicate the slope of the hill.

It may also be used as an inclinometer by placing it on the slope to be measured, and setting the spirit level until the bubble is centered. It is usually good practice to lay a board on the ground surface and take its slope to eliminate effect of small irregularities.

String Level. A string level is convenient to use over short distances. It is a spirit level fitted with prongs by which it can be hung from a string stretched tightly between two marks. Elevations may be taken from the end of the string, or by measuring down from any part of it, as illustrated in Figure 2-24.

The string used should be strong enough to take sufficient pull to remove all sag. If it is at all slack it will give false readings, showing slope at the ends of a level stretch, and level somewhere near the middle of an inclined string.

Most string levels use flexible prongs which are easily bent by light pressure. It is therefore best to check such a level before every use, and occasionally during a job. This is done by leveling a string according to it, slacking the string and reversing the direction of the level on it, and tightening the string to the same marks. If the reading is the same, the level is all right. If it disagrees, bend a prong sufficiently to move the bubble one quarter way to the center, then move the string to center the bubble. Reverse the level on the string, and repeat the procedure as above, until the reading is the same both ways.

Carpenters' Level. A carpenters' level may be used to level a string, although not as conveniently. A string leveled by a carpenters' level may be used for direct adjustment of a string level.

Leveling by Eye. In the absence of any instruments at all, an approximate level may sometimes be obtained by sighting along a horizontal board or a row of bricks of a new house, the top of a foundation wall, or marked posts standing in water.

Altimeter. Altimeters or barometers which are small enough to be carried, and sensitive enough to react to small changes in elevation, may be used for taking preliminary levels.

The aneroid barometer or altimeter contains a sealed case with a thin flexible wall or diaphragm, which is bent in by an increase in atmospheric pressure, and bent out by its contained air when the outside pressure drops. A train of levers and gears is moved by the diaphragm, so that a hand is turned on the face of the instrument in order to indicate the changes in atmospheric pressure.

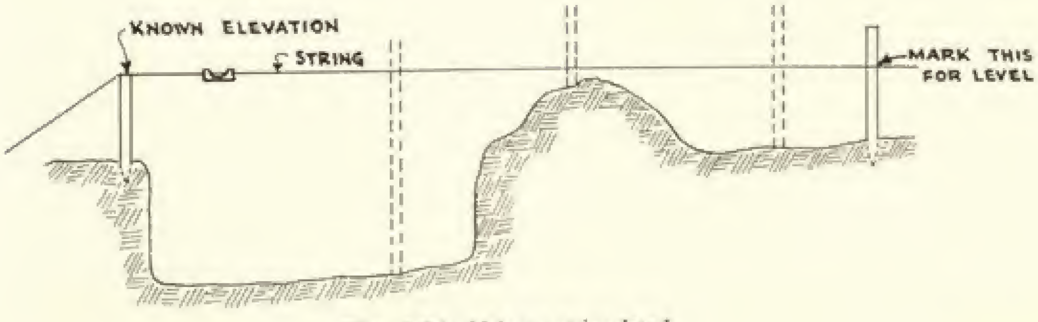


Fig. 2-24. Using a string level

This pressure drops with increasing altitude, but it is also affected by wind pressure and the movement of storms and pressure areas, so that it may vary considerably from hour to hour and day to day. In surveying, the problem is to separate changes due to altitude from those caused by weather.

This may be done by making the observations in such a short time that no important change will take place; by checking the instrument at the starting place, or some other spot of known altitude, at the end of a run, or by the use of two instruments, one of which is kept at a fixed point, and its reading recorded every hour, or oftener, while the other is used on the job, and the time of each reading noted.

In the second case, the change found may be used to correct the readings on a somewhat arbitrary basis, the most recent being the most affected. When the two instruments are used, each recording is corrected according to the barometer reading at the time it was taken.

The most convenient altimeters are engineers' pocket models, which are the size of a very large watch, and have a glass for magnifying the scale. These are expensive, difficult to repair, and rather rare.

An airplane altimeter of the sensitive type, having two or more hands, may often be purchased reasonably at an airplane instrument repair shop, where it can also be checked for accuracy. These are easily read but are somewhat more bulky to carry. Single hand airplane altimeters are slightly smaller and usually cheaper, but the scale and lack of sensitivity make them unsuitable for any but the roughest work.

Altimeters usually carry two scales on the dial—an altitude reading, calibrated in feet, and a barometer index. The hands or the dial may be turned to permit correction of the altitude reading, as required by changes in local pressure.

Airplane altimeter hands turn clockwise with increased altitude; most pocket altimeters counter-clockwise.

An altimeter is set for correct or assumed altitude when work with it is started. As it is carried up or down hill, the hands will point to higher or lower altitudes on the scale, and notes may be made of the reading wherever desired. It is advisable to tap the instrument before each reading.

Altimeters provide the quickest and easiest means of finding heights and depths in rugged and overgrown country. They are not accurate enough to be used in setting grades, except in very experienced hands.

Water Hose. A garden hose will provide an accurate level for distances it can reach. The ends are turned up so that it can be filled with water, then they are moved until the water is even with their openings. They are then at the same level and can be used for checking with little chance of error.

CHAPTER THREE

SOIL AND MUD

SOIL

SOIL AND ROCK

Soil is loose surface material. Rock is the hard crust of the earth, which underlies and often projects through the soil cover. There is no clear distinction between soil and rock. Geologically, all soils are considered to be rock formations. In ordinary usage, rock is something hard, firm, and stable.

A contractors' definition is that rock is any material which cannot be dug or loosened by available machinery, but this distinction from soil may depend more on the power, size, and digging efficiency of the machinery, than on the material itself.

Material to be excavated can also be roughly divided into three classes, rock, hard digging, and easy digging. Rock is anything that requires blasting for efficient digging by most machines. Hard digging is compacted, cemented or rocky dirt, medium clay, soft shale, rotten rock, and other material which can be dug by heavy machinery, or loosened by rippers. Easy to medium digging is any soft or fine loose deposit.

Soil. Soil is composed of particles of various sizes and chemical composition. It can be analyzed as to sizes by sifting a dried and weighed sample through a set of testing sieves, such as are shown in Figure 3-1, and weighing the material retained on each screen.

If further analysis is required for particles passing the smallest (200 mesh) sieve, it is done by hydrometer. This process is based on the fact that the speed of settlement of such particles is proportional to their size.

Figure 3-2 indicates the size particles which are included in the common soil classifications. There are several scales, in which the boundaries between different classes may vary. The differences among them are not important to the average contractor.

Fine grained soils are known as heavy, and sandy ones as light. Heavy soils may or may not permit circulation of ground water, light ones almost always do. Heavy soils are more readily softened by water. They are often called plastic soils, even when not in a plastic condition.

A plastic soil is one which can be rolled, as between the hands, into strings ⅛″ in diameter without falling apart. Plasticity is a function of soil character and of moisture content. The minimum amount of water in terms of per cent of oven-dry weight of the soil which will make it plastic is defined as the plastic limit of the soil. If no amount of water will allow it to roll into strings it is called non-plastic, with the symbol NP.

The liquid limit is minimum moisture content, in terms of per cent of oven-dry weight, which will cause the soil to flow if jarred slightly.

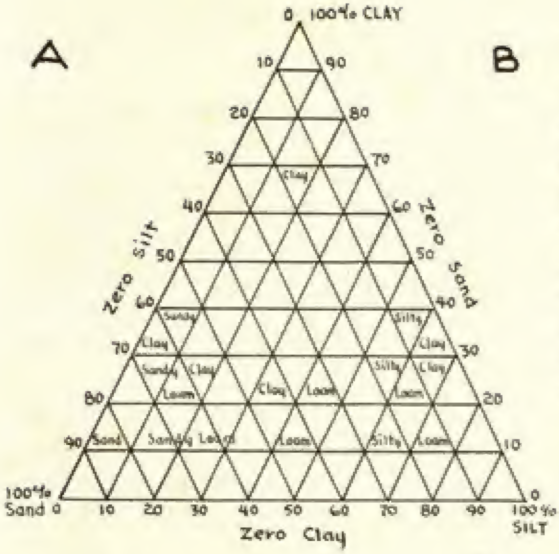
The plasticity index is the difference between the plastic limit and the liquid limit;

Fig. 3-1. Testing sieves

that is to say, the range of moisture content in which the soil is plastic.

Soils or their particles may also be classified as to grain shape or hardness, and mineral and organic content. These factors will affect their resistance to weather, sta-

A



B

CLASS	Per Cent SAND	SILT	CLAY
SAND	80-100	0-20	0-20
SANDY LOAM	50-80	0-50	0-20
LOAM	30-50	30-50	0-20
SILT LOAM	0-50	50-100	0-20
SANDY CLAY LOAM	50-80	0-30	20-30
CLAY LOAM	20-50	20-50	20-30
SILTY CLAY LOAM	0-30	50-80	20-30
SANDY CLAY	55-70	0-15	30-45
SILTY CLAY	0-15	55-70	30-45
CLAY	0-55	0-55	30-100

C

COMMON NAME	GRADE	DIAMETER Inches	DIAMETER Millimeters	PASSES SCREEN Mesh per inch	HELD ON SCREEN Mesh per inch
STONE (Boulders)	DERRICK	20" up			
	ONE-MAN	8" - 20"			
	COBBLES	2" - 8"			
GRAVEL	COARSE		20.0 - 50.0		
Concrete Gravel	MEDIUM		5.0 - 20.0		
Concrete Sand	FINE		2.0 - 5.0	3	10
SAND	COARSE		0.5 - 2.0	10	28
	MEDIUM		0.2 - 0.5	28	65
	FINE		0.05 - 0.2	65	200
SILT	COARSE		0.02 - 0.05	HYDROMETER ANALYSIS	
	MEDIUM		0.05 - 0.005		
	FINE		0.005 - 0.002		
CLAY	COARSE		.002 - .0005		
	MEDIUM		.0005 - .0002		
	COLLOIDAL		.0002 - .0001		

Fig. 3-2. Soil classifications

bility under load, wear on digging parts, and internal friction.

Most soils are inorganic, and are made up of products of decay and breaking up of rock. Organic soils and organic material in soils, are largely humus which is formed by decay of vegetation and has no definite particle size. Organic materials may also consist of lime from shells or from limestone originally formed from shells, and animal bones and excrements.

Rock. Geologically, rocks are classified

CLASS	TYPE	FAMILY
Igneous	Intrusive (plutonic)	Granite, Syenite, Diorite, Gabbro, Peridotite
	Extrusive (volcanic)	Rhyolite, Trachyte, Andesite, Basalt & diabase
Sedimentary	Calcareous	Limestone, Dolomite
	Siliceous	Shale, Sandstone, Chert (flint)
Metamorphic	Foliated	Gneiss, Schist, Amphibolite
	Nonfoliated	Slate, Quartzite, Eclogite, Marble

ROCK	WEIGHT	PER CENT OF WEAR	HARDNESS	TOUGHNESS
	lbs. per cu. ft.			
Granite	167	4.3	18.3	11
Syenite	171	3.3	18.3	15
Diorite	179	3.0	18.2	17
Gabbro	185	3.0	17.7	14
Peridotite	182	4.0	14.2	11
Rhyolite	159	3.7	18.3	19
Trachyte	170	2.9	18.1	24
Andesite	166	3.9	17.0	18
Basalt	177	3.0	17.1	18
Diabase	186	2.4	18.0	22
Limestone	165	5.0	14.1	9
Dolomite	170	5.5	14.9	9
Sandstone	164	6.2	14.4	10
Chert	159	9.4	18.2	12
Gneiss	172	4.9	17.4	10
Schist	180	4.7	16.6	13
Amphibolite	188	2.8	17.5	19
Quartzite	169	3.2	18.8	18
Eclogite	194	2.4	18.4	22
Marble	173	5.7	13.1	6

Fig. 3-3. Rock types

as to the way in which they were made. Those which solidified out of a molten state are called igneous, and are subdivided into volcanics which cooled on the surface, and plutonic which hardened deep underground.

Sedimentary rocks are built up of soil or plant or animal remains and have been hardened by pressure, time, and depositing of natural cements.

Metamorphic rocks were originally igneous or sedimentary, but have been altered by extreme heat and pressure.

Figure 3-3 contains tables classifying rocks as to type and hardness. The latter quality is quite variable, even in one formation, and may be made up of different factors, as resistance to penetration, abrasion, or crushing.

Digging Resistance. The resistance which must be overcome to dig a formation will be made up largely of hardness, coarseness, friction, adhesion, cohesion, and weight.

In digging, hardness is resistance to penetration. It is increased by close packing of soil, or filling of voids with finer particles, or lime or other natural cements. Clay soils are hard when dry, and soft when wet.

Cobbles, boulders, or hard lumps increase the power requirement for penetration. They are most troublesome when they are oversize for the machine, or packed so firmly in place that they cannot slide or rotate away from the cutting edge.

As the digging edge penetrates, friction absorbs an increasing proportion of its force. It is affected by particle size and hardness, by the amount of moisture, and the presence or absence of natural lubricants such as humus or soft clay.

Adhesion is the sticking of soil to the digging parts. It may increase the friction load substantially in wet work.

Cohesion is resistance to tearing apart. Firm or hard materials may split readily along bedding or cleavage planes so that they can be dug rather easily from the proper direction. Relatively soft clay banks may be very difficult to dig because of strong and uniform cohesion. A tough formation lacking planes of weakness is described as "tight."

WEIGHTS OF MATERIALS

(ONE YARD — WEIGHTS IN POUNDS)

MATERIAL	1 YARD 27 CU. FT.
ASHES — PILED DRY	945
BRICK BATS	1485
CEMENT — PORTLAND	2538
CINDERS	1485
CLINKER — PORTLAND CEMENT	2295
CLAY — DRY, IN LUMPS	1701
CLAY — COMPACT, NATURAL BED	2943
COAL — ANTHRACITE	1512
COAL — BITUMINOUS, R. OF M. PILED	1485
COAL — BITUMINOUS SLACK, PILED	1350
CONCRETE — READY TO POUR	3996
DOLOMITE — CRUSHED FINE	2565
DOLOMITE — BROKEN LUMP	2565
EARTH — LOAMY, DRY, LOOSE	2025
EARTH — DRY, PACKED	2565
EARTH — WET (MUD)	2970
GYPSUM — CRUSHED TO 3"	2565
GYPSUM — CALCINED	1620
GRAVEL — DRY, LOOSE	2970
GRAVEL — DRY, PACKED	3051
GRAVEL — WET, PACKED	3240
IRON ORE — 60% IRON	8100
IRON ORE — 50% IRON	6750
IRON ORE — 40% IRON	5400
LIMESTONE — RUN OF CRUSHER	2565
LIMESTONE — FINES OUT	2700
LIMESTONE — 1 ½" OR 2" GRADE	2295
LIMESTONE — ABOVE 2" GRADE	2160
PHOSPHATE ROCK	2160
SAND — DRY, LOOSE	2565
SAND — WET, PACKED	3240
SHALE — BROKEN	2295
SLAG — BLAST FURNACE, BROKEN	3726
SLAG — OPEN HEARTH, CRUSHED	2835
SLAG — GRANULATED, DRY	1025
SLAG — GRANULATED, WET	1566
SULPHUR — BROKEN	1620

Fig. 3-4. Weights of materials

Weight may limit the amount which can be dug or carried in a bucket or body and the speed with which the load can be hoisted or transported. It is a critical factor in selection of dragline and clamshell bucket sizes, and in regard to the length and angle of the boom which carries them.

Figure 3-4 gives approximate weights per cubic yard of some common materials.

Rolling Resistance and Grades. Most excavated material is transported in trucks or scrapers partly on pit floors or unpaved haul roads. The weight that can be carried, and the speed made by any given unit, are affected by the resistance of the surface to the wheels or tracks.

Table A, Figure 3-5, indicates the differences in rolling resistance to a typical rubber tired machine on various types of surface. A resistance of twenty pounds to the ton is roughly equivalent to that offered by an upgrade of one per cent.

If the machine in the example were equipped with larger tires, or if pressure were reduced in standard tires for the soft footing, rolling resistance would be diminished in the higher brackets.

Poor footing reduces production substantially and also increases machinery maintenance cost.

A down grade may counteract power loss on poor footing, or on good footing give added force, of at least twenty pounds per ton for each per cent of slope.

Tractive Efficiency. Tractive efficiency is a measure of the proportion of the weight resting on tracks or drive wheels which can be converted into movement of the vehicle, dependent upon the coefficient of friction of its roadway.

On any given surface, it can be increased by the use of wider or longer tracks; or larger or more numerous tires. With any

A TABLE I

A hard, smooth, stabilized, surfaced roadway, without penetration under load. Watered. Maintained.	40 lb./ton
A firm, smooth, rolling roadway, with dirt or light surfacing, flexing slightly under load or undulating. Maintained quite regularly. Watered.	65 lb./ton
A dirt roadway, rutted, flexing under load, little if any maintenance. No water.	100 lb./ton
Rutted dirt roadway, soft under travel, no maintenance. No stabilization.	150 lb./ton
Soft, muddy, rutted roadway — or in sand. No maintenance.	250 to 400 lb./ton

B TABLE II

TYPE OF ROADWAY	FACTOR
Rough concrete	.88 to 1.00
On clay loam: dry	.50 to .58
On clay loam: wet	.40 to .49
Rutted clay loam	.40 to .44
Gravel road	.36
Rutted sandy loam	.20 to .35
Loose sand	.20 to .35
Packed snow	.20
Ice	.12

Fig. 3-5. Rolling resistance and tractive effort

TABLE I

	SWELL	VOIDS
Clean sand or gravel	5 to 15%	4.75 to 13 %
Top soil	10 to 25%	9 to 20 %
Sandy, clayey loam	10 to 35%	9 to 26 %
Good common earth	20 to 45%	17.7 to 31 %
Clay with sand or gravel	25 to 55%	20 to 35.5%
Clay-friable and light	30 to 60%	23 to 37.5%
Clay-dry, lumpy and tough, with rock	35 to 70%	26 to 41 %
Shale and soft rock	40 to 85%	28.5 to 44 %
Hard rock - well to poorly blasted	50 to 100%	33.3 to 50 %

The loose or aerated part of the load uses space as a percentage of the full heaped pile and is shown above in the second column as "voids".

TABLE II

As a means of simplifying the consideration of these factors, they have been reduced to a representative four as follows:

Sand	10% Voids
Common earth	20% Voids
Clay	30% Voids
Shot rock	40% Voids

TABLE III

Excavation, or place yards may be judged then to represent:

In sand	90% of the heaped maximum capacity
In common earth	80% of the heaped maximum capacity
In clay	70% of the heaped maximum capacity
In rock	60% of the heaped maximum capacity

TABLE IV

Loose yards will represent:

In sand	111% of bank yards
In common earth	125% of bank yards
In clay	143% of bank yards
In rock	167% of bank yards

Fig. 3-6. Soil swell and shrinkage

degree of tractive efficiency, traction, or the total amount of driving push, can be increased up to a point by increasing the proportion of vehicle weight on the drive wheels.

Table B gives the tractive efficiency of an average off-the-road hauler on various surfaces.

Tractive efficiency is affected by the amount of friction between tire and soil surface, and by the cohesion of the soil.

Swell. When soil or rock is dug or blasted out of its original position, it breaks up into particles or chunks, which lie loosely on each other. This rearrangement creates spaces or voids, and adds to its bulk. The increase is called swell.

Measurement of earth in its original position is in bank yards, and after shaking up is in loose yards. Relative volumes of some common earths are indicated in Figure 3-6.

When soil is placed in a fill, and thoroughly compacted by rolling, it will shrink, the amount depending on its character, its structure in the bank, the thickness of fill layers, and the weight and type of roller. Blasted rock will retain some swell, while ordinary loam may be reduced to about ninety per cent of its bank volume. Measurement in the fill is described as compacted yards, or yards after shrinkage.

Capacities of buckets, bowls and bodies are in loose measure. Large jobs are figured on bank and compacted yards; while small jobs, or delivered prices of earth, are more likely to be based on loose yards. It is important that the type of yard be clearly understood in any arrangement made.

Mine and quarry output may be measured in tons, which are converted to yards when necessary by measurement, or use of tables similar to that in Figure 3-4.

CAPACITY AND OUTPUT

Most excavating and hauling units have a bucket, bowl, or body which is loaded, moved, dumped, and returned to the loading point. The complete set of operations is known as the working cycle.

The probable production of such a machine can be calculated by multiplying its capacity by the number of times it can go through its cycle in a given period.

Other machines such as hydraulic dredges and bucket or belt conveyors produce a more or less continuous stream of material. Their output may be calculated according to an average cross section of the stream multiplied by its speed or on a basis of buckets per minute.

Production may also be determined by measurement of the material moved during a time period; either in the bank before

BODY SIZE LENGTH WIDTH	HEIGHT SIDES	CAPACITY CU. YDS.
9'-0" × 7'-0"	15 ½"	3
	20 ⅞"	4
	25 ¾"	5
9'-6" × 7'-0"	14 ⅜"	3
	19 ½"	4
	24 ½"	5
10'-0" × 7'-0"	13 ¾"	3
	18 ¾"	4
	23 "	5
10'-6" × 7'-0"	15 ½"	3 ½
	17 ½"	4
	20 ⅛"	4 ½
	22 ¼"	5
11'-0" × 7'-0"	16 ¾"	4
	20 ⅞"	5
	25 "	6
12'-0" × 7'-0"	15 ½"	4
	19 ½"	5
	23 "	6
	31 "	8

Fig. 3-7. Body capacities

moving, or in the hauling unit or fill.

Any method used must take careful account of all factors which may affect either the capacity or speed of the unit.

Capacity. Most buckets and bodies are rated by the manufacturer as to carrying capacity in loose yards. This rating may be water level (the yardage of liquid which could be carried if it didn't leak out), line of plate or struck measure, which is water level or water level plus the space between parts of the rim which project above its low point, or heaped.

Shovel dipper buckets and truck bodies are normally rated at water level, carrying scrapers at both struck and heaped measure, and clamshells at water level, line of plate and heaped.

Body capacity should be indicated by a plate. It is usually in yards, but may be in feet. It ordinarily does not include sideboards, or other removable extensions which increase its volume. The extra load between the boards may be found by the proportion between the heights of the body-wall and of the board. For example, if a body with three foot sides holds six yards, a one foot sideboard on each side will increase capacity by two yards.

If there is no plate, size can be determined by measurement of the inside length, width and height, usually in feet and fractions of feet. These are multiplied together, to obtain cubic feet, which are divided by twenty-seven to get cubic yards.

The table in Figure 3-7 gives dimensions of the water level capacities of some body sizes used in trucks.

Heaps. The heap on top of a load can be measured only approximately because of its shape. It is usually calculated on the basis of an assumed even slope of the material. On a truck body the slopes from opposite sides are continued until they meet, while on a scraper they may be cut off horizontally at a height beyond which they are not apt to build.

In general, the volume of a heap is determined by the slope of the material and the area of the body. A steep slope and a wide body give maximum yardage.

Occasionally very large heaps can be carried. A dragline bucket in wet chunky humus may pick up a load which is double the struck capacity.

Some contractors figure that the volume of the heap balances the voids in the load so that heaped loose yards equal level bank yards. Because of the wide variations in both swell and relative volume of heaps and level loads, this rule of thumb may be wrong more often than it is right.

Container Efficiency. An excavator may not be able to fully load its bucket or bowl, because of hard digging, poor traction, inadequate power, heavy material, or other factors. A hauling unit may be run partly empty to save strain on rough ground, or to enable it to climb steep grades.

When material is coarse in proportion to bucket size chunks may be partly supported by the sides and each other, leaving excessive voids and reducing the load below that indicated by bucket capacity.

The proportion between container capacity and its actual load is called the bucket, bowl, or body efficiency factor. This factor is included in calculations only when indicated by the special conditions listed above.

Irregular Loads. Loads pushed by a bulldozer blade are rather shapeless and difficult to measure. They can best be estimated by counting the number of full passes required to dig a known yardage of a bank; or by placing a known number of loads in a pile, and measuring the pile.

The first result will be in bank yards, the second in loose yards.

Work Cycles. The work cycle may be timed as a whole in figuring output for existing conditions. For accuracy it is necessary to take the average of a large number of passes as there may be a considerable variation among them.

If a study is made of a cycle, either to find a way to speed it up, or to use its time intervals as a basis for figuring production under different conditions, it can be broken down into individual operations which are timed separately.

A study of bulldozer and of scraper operation may include some or all of the divisions listed below. Each one should be timed. Digging and traveling distances should be measured. A record should be made of all grades, as these machines are much less efficient going up hill than down.

Bulldozer	*Scraper*
Dig	Load
Shift into second	Shift
Transport	Transport
Dump	Shift
Shift to reverse	Spread
(raise blade)	Shift
Return	Deadhead to turn

Bulldozer (Cont.)	*Scraper (Cont.)*
Shift to low	Turn
(lower blade)	Return to digging area
	Deadhead to turn
	Turn
	Get to loading position
	Shift into low
	Wait for pusher

Machine Efficiency. Non-working time such as delays for moving the machine, minor repair adjustment, rest, getting instructions, or looking at grade stakes is not averaged into cycle time. It is considered separately as the efficiency factor of the machine. It may work out between 70% and 85% for short periods with expert operators on a properly run job, with machinery in good condition and weather favorable.

A convenient way of making rule-of-thumb allowance for efficiency of about 83% is to consider that an hour contains only fifty working minutes. On this basis, a machine with a thirty second cycle cannot be expected to perform it more than one hundred times an hour.

If two machines are interdependent, the efficiency factor is usually lower so far as the job is concerned. If two eighty per cent efficient machines are down at the same time every time the efficiency factor remains at 80%. If they are down separately each time the factor drops to 60%.

As the period under study becomes longer efficiency drops steadily as weather, work sequence stoppages, and major overhauls must be considered. Time losses can be further increased by inefficient management, bad pit layout, poor morale of employees, or other unfavorable conditions.

Output Formulas. A formula which can be used for figuring production of any machine with a regular cycle is:

$$\text{OUTPUT, yards per hour} = \frac{Q \times K \times E \times 60 \times f}{Cm}$$

Where: Q = capacity, either struck or heaped
K = efficiency factor of bucket or body
E = efficiency factor of machine
60 = sixty minutes in an hour
f = soil conversion factor
Cm = cycles per minute

If the result is to be in bank yards, f has a value obtained from observed swell, or from Table 3, Figure 3-6.

If the result is to be in loose yards, f equals one, and can be dropped from the equation.

The factor K is not required when full, solid loads can be taken.

If efficiency is approximated at ⅚, 50 minutes are used instead of 60, for the hour.

Under these conditions, the following simplified formula can be used:

$$\text{OUTPUT, loose yards per hour} = \frac{Q \times 50}{Cm}$$

When timing machines whose cycle is less than a minute it is more convenient to figure it in seconds. This is done by multiplying the number of minutes by 60, and using Cs—cycle time in seconds—instead of Cm. With these substitutions, the formula will be:

$$\text{OUTPUT, yards per hour} = \frac{Q \times K \times E \times 3600 \times f}{Cs}$$

Or simplified to:

$$\text{OUTPUT, loose yards per hour} = \frac{Q \times 3000}{Cs}$$

Additional data on output will be found in Chapter 11 and in the Appendix.

MUD

Before proceeding with the details of various types of excavation, it is in order to consider some of the general problems. Mud is one of the most important of these.

NATURE OF MUD

Water Content. Mud is soil saturated with water to such an extent that it loses its structure and takes on some of the properties of a liquid. Even the driest soils contain some water in very thin films, and moderate additional amounts may give added firmness by acting as a binder. But when the quantity of contained water is sufficient to build up water films around the grains thick enough to serve as a lubricant so that they can move freely on each other, the soil becomes mud.

Particle Size. The quantity of water necessary to turn mineral soils into mud varies with the size, shape, and arrangement of the particles. Small grains have much less volume in proportion to the thickness of the water film they hold than have large ones, and therefore they form more fluid muds. Sharp angular grains have projections which penetrate the film and interlock, and large grains and pebbles develop high enough contact pressures to cut through the film. If there are enough fine particles in a mixed soil to prevent the coarse ones from touching, the mud will have the qualities of the fines.

A fine-textured (heavy) soil such as clay will also remain saturated much longer than a coarse one, as the spaces between the grains are so small that water moves through them very slowly.

Humus. Humus, or peat, which is decayed organic material, absorbs water somewhat as a sponge does, in large quantities, and holds it stubbornly against evaporation and drainage. When saturated, nearly pure humus, as found in some swamps and peat beds, resembles a jelly, fibrous or smooth in texture, and black or brown in color. It is the slipperiest and most treacherous of the muds. It dries very

slowly, with shrinkage of 50 per cent or more, to a light, fluffy soil. When mixed with inorganic soils, as in topsoil and mucks, it greatly reduces their load bearing qualities and makes them muddier under wet conditions.

Quicksand. Quicksand is usually fine sand or silt through which water is moving upward with enough pressure to prevent the grains from settling into firm contact with each other. It provides practically no support for machinery unless its weight is distributed over a large area by platforms.

Making Mud. When undisturbed, inorganic soil is usually quite closely packed, with its grains fitted together closely, and often lightly cemented by mineral deposits. When it is dug up or pushed around, the grains are shaken away from each other into a loose structure. In this condition it can quickly absorb a large quantity of water and become a very soft mud. As it dries, the grains settle together so that less water is absorbed with each subsequent wetting. If it is compacted by rolling, tamping, or vibration before being soaked, it may become even more water resistant than in its original state.

When a firm, dry soil is covered with water, it gradually absorbs some of it and expands in volume, but it never becomes as soft as if disturbed before wetting.

If a firm, fine textured soil has a film of rainwater on its surface, and is passed over by a vehicle tire, the water will be forced between the surface particles and the resulting mud will be wiped off and pushed aside, leaving a new surface exposed to the next raindrops and wheel passage. Repetitions of this result in a slippery road, ruts, and mudholes.

Frost. When soil freezes, the expansion of ice crystals between the particles pushes them out of place. When the soil thaws, it is likely to become a slippery, structureless mud, often resembling toothpaste in consistency. It ordinarily firms up fairly quickly, particularly if vibrated by a heavy rain, but may persist for several months when upward seepage of water prevents settlement. In its extreme condition it will not support loads, and is made more dangerous by its occurrence in places that are normally firm, and under sod which bridges and hides it. Such places can be detected by sounding with a crowbar, and should be avoided or treated with the same precautions as soft swamps.

In northern winters, frost may stabilize a swamp so that it can be worked easily. Ice and frozen earth are liable to be variable in thickness and treacherous because of snow cover and the heat of decay of organic material, but any traveled route will gain in stability as long as freezing continues.

Mud from thawing is apt to render dirt road surfaces slippery, particularly on sunny slopes. Early mornings such roads are often frozen hard, and work must be done, then, in cloudy weather or at night. Tire chains are useful but may not be adequate.

Sand. Clean sand is as troublesome as mud to two-wheel drive vehicles. It can be stabilized with pneumatic tired rollers and plenty of water, but the surface will loosen up as soon as it dries. Tires spin and dig down into it rapidly with a jerking motion that is very damaging to the drive mechanism. All-wheel drive vehicles ordinarily have less difficulty with it, but it consumes considerable power. The general problem is one of getting traction without digging in, but there is no danger of simply sinking as in mud. Partially deflating the tires may help; smooth tires will do better than those with tread as they will not dig down as readily. Mats of brush, wire, grass, or a thin layer of dirt may suffice to give traction.

Tracked vehicles can travel on sand without difficulty, but if equipped with grousers, care must be taken about pulling

heavy loads that may cause tracks to spin, as they will then hang up quickly. The silica which makes up most sand is very wearing to the track parts, particularly when particles are angular.

Work Delays. Mud is an impediment to work in many ways. Deep mud causes equipment to bog down and to become useless until pulled out, and a film of mud may render firm footing dangerously slippery. Mud sticks to shovel buckets and truck bodies instead of dumping, and builds up in chains and tracks until they jam. It holds objects lying on it by powerful suction so that they become difficult or impossible to lift. When frozen it can lock together and immobilize the most powerful machines. And it is much heavier than the same amount of dry soil.

The most severe mud conditions are encountered in swamps because of permanently saturated conditions and the usually high organic content of the soil, but because the contractor expects this and is prepared, fewer difficulties arise than when mud appears on drier jobs.

EQUIPMENT FOR MUD

Mud trouble can be reduced by using proper equipment. In general, crawlers are preferable to wheels; tracks should be the longest and widest obtainable; tires should be big, soft, and cleated; and units should be the smallest that will do the work. All-wheel drive is desirable for trucks.

The ability of a machine to stay on top of soft ground is affected by its ground pressure, which is usually measured in terms of pounds weight on each square inch of ground contact; shear, which is the load on the edge of the track or tire; and total weight.

Ground pressure is the most important factor in loose soils such as sand or dust. Shear is most important when a soft soil is protected by a harder crust or sod. It is increased when the machine is tipped, and when it pushes a load. Total weight affects deep mud which may creep or flow from under the machine.

Grousers or cleats cut and churn up their footing but are necessary to get a grip on slippery surfaces.

Some wheel tractors can be fitted with temporary metal and rubber tracks which enable them to work in fairly soft places.

Crawlers may have oak planks or four-by-fours bolted to their pads so as to project several feet on the outside. These will stand up well if kept on soft ground and give excellent flotation. They cannot be used with a dozer that has outside push arms.

Special vehicles, such as the military weasel and the swamp buggies used for exploration by oil crews, are very useful in supplying fuel and other essentials to machinery working in swamps.

TEMPORARY ROADS

Wheeled Equipment. Wheeled equipment is best kept out of swamps unless they are frozen, dried out artificially or by drought, or have roads built into them. The minimum road is a strip in which the soft spots are stuffed with brush or bridged with planks. If poles are used, they should be closely fastened so that they cannot work apart and let wheels down between. Whenever possible surface poles should be at right angles to the direction of travel.

Pole Tracks. Poles may also be used as tracks to be straddled by dual wheels. They should be straight, free of stubs or sharp projections which might cut tires, and should be large enough so that they cannot pass between the tires toward the hub, and small enough so that they will not slip sideways out of the groove between the tires. The poles should be overlapped at their ends so that the wheels will not be left without support while passing from one to another.

Front wheels may be placed on skids or

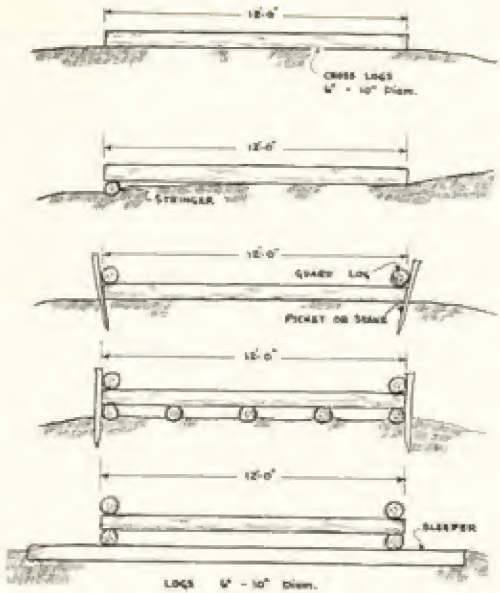


Fig. 3-8. Corduroy road cross sections

runners and chained down. If the mud is not very deep, they may be left to make their own way.

This procedure is for short emergency moves only.

Corduroy. A corduroy road can be built to support heavy machinery on very soft ground. It consists of logs or half logs laid across the traveled way, touching each other. They may be laid directly on the ground, on one or more stringers running lengthwise, or on both stringers and longer cross logs, called sleepers. Several constructions are shown in Figure 3-8.

A minimum width of 12 feet is recommended for one way traffic, although it might be possible to get by with ten. Curves should be two to four feet wider. Cross logs may be extended beyond the road edge for additional stability.

Logs six to ten inches in diameter are generally strong enough for the work, without being excessively heavy. Thinner ones may be used as stringers. Heavier sizes may be split for cross logs, or partly buried for stringers.

The upper surface of cross logs should be smoothed by removal of stubs and bumps, and perhaps planing down with adze, ax, or ripsaw.

Guard logs are desirable to prevent vehicles from sliding off, to reinforce the road structure, and to retain any surfacing which may be added. Picket stakes may be placed to hold guards in position, and to bind cross logs to the outer stringers. Edges may be bound together by heavy wire, by cable, spikes, or lag bolts. Such fastenings are important when the road surface is well above the ground, where the mud will not act to hold it in place.

Drainage ditches may be dug on one or both sides to remove standing water. These should be kept from three to ten feet away so that mud will not flow into them from under the logs. In very thin mud their use is inadvisable.

When a drainage channel or small stream must be crossed, the stringers can be increased in number and strength and set on sleepers on each side of the channel so as to serve as a log bridge. If clearance is doubtful, metal pipe may be used to carry the water under the stringers.

Corduroy roads are quick and fairly easy to construct if logs are on the site, and usually are very strong. However, their surfaces are extremely rough and it is advisable to cover them with gravel or other surfacing if they are to have much use. This saves damage to both machinery and road.

A corduroy road made of oak, cypress, or other strong and rot resistant wood may have a very long life. Some soft woods, such as poplar, will rot out in two or three years. If mixed species must be used, the inferior ones will give their best service as stringers or sleepers.

Saplings or brush may be wired into tight bundles and used instead of logs for light corduroy.

Plank Roads. Plank road constructions are shown in Figure 3-9. These are usually

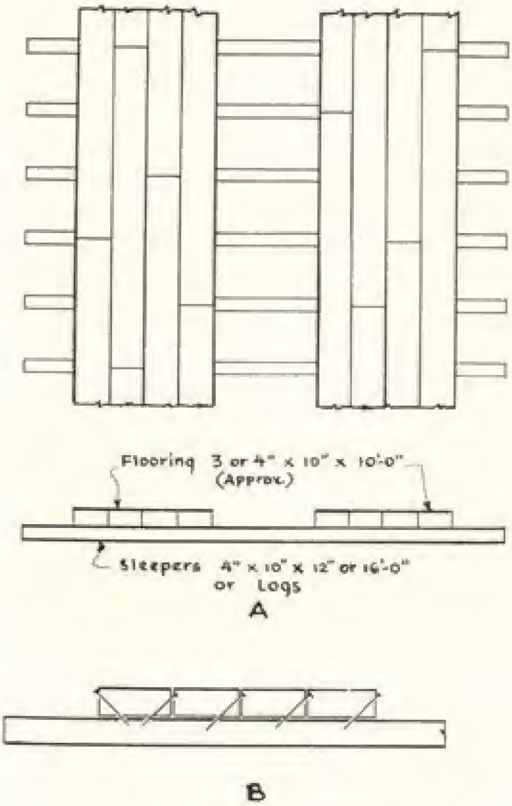


Fig. 3-9. Plank road

more expensive than corduroy, but are easier to lay and provide a smoother surface. Rain or mud may make them very slippery so that sanding will be required.

Nails should be driven diagonally from the sides of the tread planks, as in (B), to prevent them from working up and puncturing tires. Even with this precaution, frequent inspections for nails and splinters should be made. If the wood is hard, nails should be soaped or greased before driving. Splitting may be reduced by making thin pilot holes with an electric drill.

Railroad Ties. Used railroad ties are often available in large quantities at cordwood prices, or less. They can be used for roads and platforms, as well as for supports, blocks, and braces. They are usually of hardwood, 8½ feet long, and about 7″ by 9″. Longer ones, used under switches, are occasionally available.

Heavy vehicles are seven, eight, or more feet wide, and cannot safely be used on a single row of standard ties. Several systems are used to obtain greater width, but none of them is entirely satisfactory. A center stringer Figure 3-10 (A), of two logs securely fastened together permits using two rows of ties. Alternating side ties on a single center stringer makes a surface too sketchy for normal use, but will serve as good support for plank treads. The slightly staggered construction shown in (B) provides a wider surface than a straight row.

Stone Walls. Sometimes a stone wall extending into a swamp may be profitably used as a base for a road. It may be wrecked and scattered over the desired width by hand labor or by a bulldozer. The dozer can advance a limited distance, pushing and twisting the top stones to each side, and walking on them until the going gets too rough. It should then back out, some fill should be dumped, and the dozer push it into the hollows so that it can advance farther. The large stones, and the

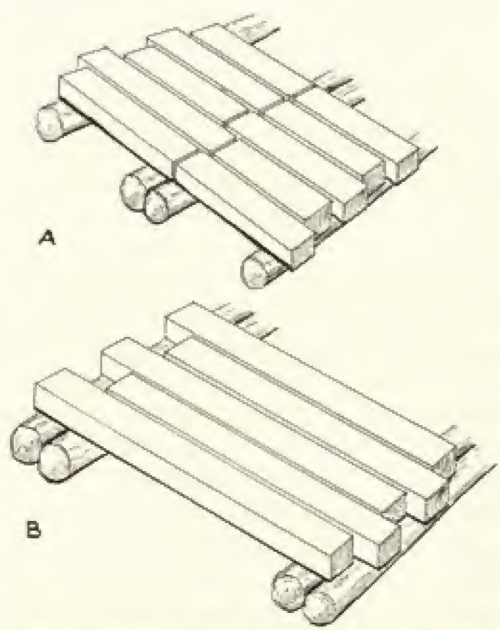


Fig. 3-10. Railroad ties for truck road

age of the structure, assure stability and large amounts of fill are saved.

Surface Protection. A wet soil with good load bearing qualities which might be readily churned into mud, may be protected by a few inches of gravel, spread before traffic uses it. Two feet of broken rock with a skin of gravel may carry heavy traffic for a while over almost any mud. Brush mats or pole corduroy under the rock give added stability. Between these extremes is every type of condition and cure.

Fill for mud coverage should be as dry as possible and possess good packing qualities. It should be put on in sufficient thickness so that truck tires will not reach through to mix it with the mud. It is strengthened by compacting with a roller, jeep, or empty truck before carrying loaded trucks. A layer of fine textured, hard packing soil topped with gravel is often satisfactory, but clean broken rock in coarse sizes up to one half the fill thickness, is longest lasting.

Flat stones should be placed on edge, whenever possible, so that they will not shift under load. Natural drainage must not be blocked. Iron or steel culvert pipe is most satisfactory on soft bottoms.

SUPPORTS

Swamp Surfaces. Most swamps are covered with vegetation that gives them some surface stability. Wet swamp sod in which a man's feet will sink slightly, ordinarily will support a light crawler machine moving steadily across it in a straight line or gradual curves. Crossing should be tried with caution, particularly if the unit has narrow tracks, or high grousers which tend to cut the sod. Sharp turns, if necessary, should be made in the firmest or best matted sections, or extra support should be provided. Bushes and close growing saplings which can be walked down by the machine, without cutting, provide excellent natural support.

Although a shovel can be safely walked on quite soft ground, it cannot stand or work on it. If standing, its weight slowly displaces mud beneath it, and as that creeps away, the sod or crust left without support shears and breaks. This process is greatly accelerated by working, as the vibration, the variable load, and the twisting reaction to the swing all cause the machine to settle, particularly at the end where the loads are picked up.

Platforms. If footing is too soft for safety, it can be improved in various ways. The safest and most satisfactory support is a set of platforms—also called pontoons, rafts, or mats.

A revolving shovel can work on very soft ground when supported by a set of platforms. They usually consist of wood platforms upon which the shovel can stand, provided with side rings or loops or cross cables, by means of which they can be picked up by a chain across the shovel bucket, or directly by the bucket teeth. Platforms should be trucked as near the job as possible, then dragged to it by a tractor or the shovel, or carried by the shovel.

To walk a shovel across an open swamp on platforms, pick up two or more of them and lay them on the mud, as shown in Figure 3-11 (A). Move the shovel to the front of these, then pick up the remaining platforms and lay them ahead of the shovel as in (B). The minimum number to be used is three—two to stand on and one to move. Four are safer and easier to use, and the maximum is the number the shovel can reach when they are laid in a line behind it. Most draglines use three or four on small jobs, and four to six on large ones.

The shovel then walks to the front of the platforms, (C), and picks up those behind it, starting at the rearmost, and lays them in a line in front of itself. In (D), the platforms are laid in a curve to avoid a rock. (E) to (G) show patterns for laying them

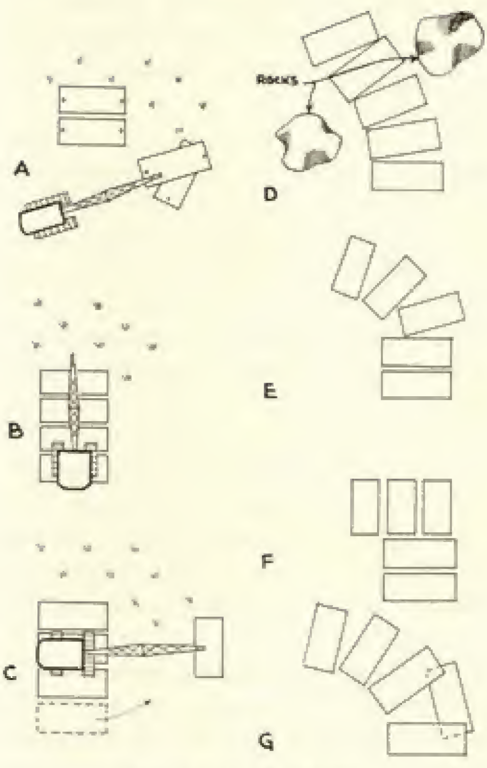


Fig. 3-11. Platforms

in sharp curves. These should be avoided where possible, as the turning of the shovel has a destructive grinding action, and overlapping the platforms causes severe strains, particularly if they are equipped with side rails.

Shovel Rigs. Techniques of working from platforms vary with the type of shovel attachment being used. The most efficient swamp worker is the dragline. Its long reach enables it to keep well away from the hole it is digging, and to pile spoil far enough away to reduce slumping back into the pit or against the shovel. The sliding action of the bucket during digging and hoisting reduces trouble with suction.

A dragline ordinarily stands at the back of its line of platforms and digs at the rear or sides. When its work from one position is finished, it walks ahead one or more platform widths, then picks up the platforms behind it, and swings and places them in the front; repeating this process as often as a move is required.

A pull shovel is used in the same manner. It is not as well suited to mud work because of its shorter digging radius, and particularly because of its inability to pile the spoil well back, but it shares the dragline's advantages of walking away from its work and sliding the bucket to break suction. A pull shovel is usually able to pick up platforms by means of a cross cable, by hooking the bucket teeth under it, which saves the dirty job of chaining them.

A clamshell has almost as much reach as a dragline, and can work without dragging debris, such as roots, stumps, and boulders, up against the platforms and itself. However, it has the severe handicap of pulling the bucket straight up, which in sticky mud requires overcoming suction more resistant than the weight of the bucket and load. Digging is best done off the rear or sides of the platforms, but the ground ahead can be graded before placing the platforms.

Dipper sticks are seldom seen in swamps. They can do shallow digging and uprooting of stumps behind and at the sides of the platforms, but any serious digging must be done at the front, and there is limited to fairly narrow ditching in firm mud. The spoil must be dumped far enough to the side so that platforms can be placed across the ditch. Even with extra wide platforms, the weight is liable to cause the sides of the ditch to cave or flow in, and the footing for the platforms is not secure.

The spaces between platforms will vary with the nature of the footing. For very soft conditions, they should be placed in contact with chains fastening them together, or even laid in two layers, as in Figure 3-12 (A).

For ordinarily soft or suspicious ground, the widest spacing allowed should be that

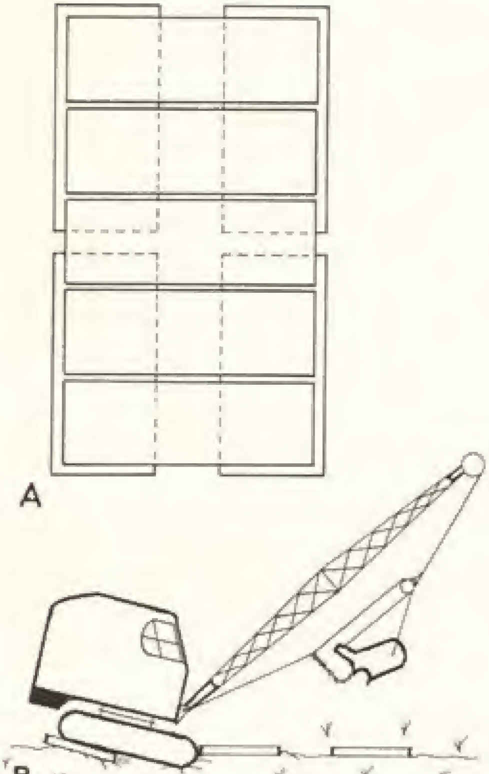


Fig. 3-12. Overlapping and spacing platforms

which will enable the shovel to reach the next platform before its center of gravity reaches the edge of the one it is on, so that the shovel will not tip forward, as in (B), so much that the track will push the next platform instead of climbing on it.

Blocking. Normally, a shovel can be worked on platforms without blocking. There is always a risk, however, that a dragline, or particularly a pull shovel, will unexpectedly hook into something solid and drag itself off the platform before the operator realizes what has happened. If the platforms are slippery with mud or ice, this danger is greatly increased, and the machine is also likely to slide sideways in reaction from swinging.

If the platform is the spaced plank type, an effective block can be made of a wood wedge fastened to a stub of plank that fits between the platform planks. The wedge changes most of the forward thrust of the shovel into a downward one against the platform, and the plank anchor should hold it in place. One of these should be placed in front of each track.

On a solid platform, wood wedges chained to the platform, as shown in Figure 3-13 (A), are effective. For side protection, plank rails, permanently bolted to the side edges, or held there with pins, as shown in (B), are usually adequate.

Chaining to Platforms. For extreme conditions, the shovel may be chained to the platforms. There are many ways to do this, of which one sample is shown in Figure 3-14. The platforms have a cable loop at each corner, by some of which the two platforms are chained together. To the outer corners of the truck frames are welded brackets holding rings or hooks. Chains are fastened to these and to the corresponding outer corner loops of the platforms, and are drawn up taut with chain tighteners in the rear. The tightness is important, as the momentum of a sliding shovel will break chains or tear out loops which would hold against a direct pull.

All accessories, such as blocks, rails, chains, and tighteners that are to be used

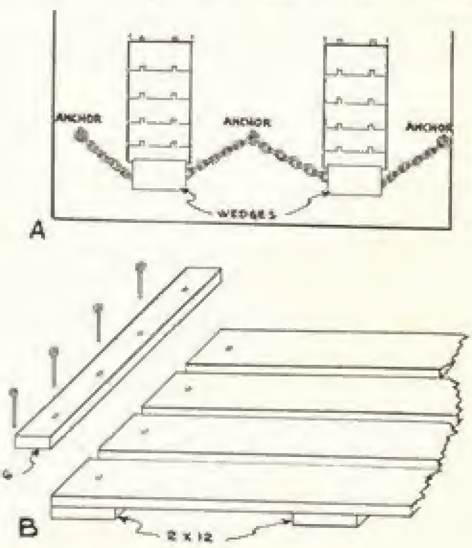


Fig. 3-13. Blocks and side rails

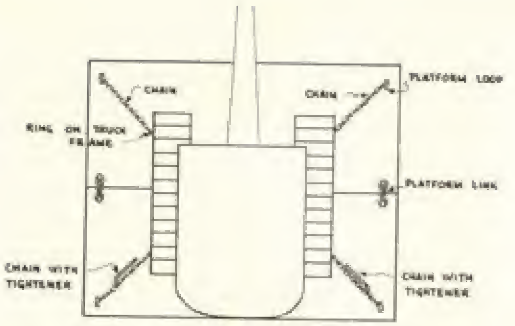


Fig. 3-14. Chaining to platforms

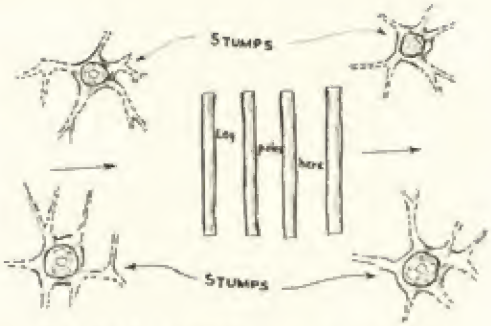


Fig. 3-15. Support by roots and poles

in mud, should be kept painted some brilliant color (not green). They are very easily lost and dug under, particularly if some emergency interrupts the routine of their use, and the bright color will greatly increase chances of salvage.

Platforms can be used efficiently only in places where the shovel has room to swing. If trees prevent swinging they must be cut, or other methods used to support the shovel.

Suction. Handling platforms or other objects in mud is greatly impeded by the weight of mud clinging to them by atmospheric pressure, which is felt as a suction. A platform 4½ × 12 feet carries an atmospheric pressure of over fifty tons. When air can flow under it freely, the pressure is upward as well as downward, and is not felt in lifting it. If air is sealed from the bottom by mud, then the lift of the shovel merely serves to reduce the weight of atmosphere and platform on the mud beneath, causing mud at the edges which carries the full atmospheric load to squeeze in under it. A thin mud will flow quickly, a thick tenacious one may stretch but not flow and keep the air locked away from the bottom.

If the suction is too strong to break by a direct lift on the whole platform, the pull should be concentrated on one side or one corner. If the mud seal is broken at one spot, it should shear off from the whole under surface. The platform might also be lifted and dragged at the same time. Suction presents comparatively little resistance to sliding, and this motion greatly increases the shearing effect on the mud seal. Unfortunately, a dragline is apt to make a pile of mud and debris which would prevent the platform from sliding forward, and the lattice boom is apt to twist or collapse if subjected to heavy side strain.

A method of releasing is to catch the forward edge with the bucket teeth and hoist while pulling back enough to keep hooked.

Root Mats. Trees growing closely in swamps usually form a mat of interlocked roots that will support crawler equipment, but will give it a rough trip. Openings may occur where the roots are lacking, which may be crossed by means of green saplings laid across the path of the machine, as indicated in Figure 3-15. If it is necessary to remove trees to give the shovel space to get through, they should be cut as closely to the ground as is possible, as the shovel might sink while going over the stump and get hung up on it. Logs laid on each side of the stumps across the line of travel are protection against this.

In a swamp studded with stumps, or rock, platforms break up very readily. The spaced plank type, which is generally preferred because of light weight and reduced suction, will break if used across a stump or heavy buttress root, and the heavier types will strain and splinter. Some operators prefer to pull the stumps before walking over the spot, thus exchanging the platform-breaking obstacles for a wet and uncertain footing.

It is dangerous to move a machine onto platforms which are placed with one side on firm ground and the other side in loose mud. The mud side may sink enough to cause the shovel to slide to that end and tip over. The soft side may be braced with platforms or logs, or the firm side can be ripped up, before placing the platforms.

Poles. A shovel may be walked and worked on fairly soft footing by the use of saplings instead of platforms. These should be of firm wood, preferably green, two to ten inches in diameter, and long enough to project two or more feet beyond the tracks on each side. They should be laid across the path of the shovel, widely spaced on fairly safe ground, a foot or two apart on soft. An extra precaution is to place outrigger poles under their ends, parallel to and outside of the machine's path. When the shovel has passed over the poles, they may be retrieved and used again, but the mortality rate is usually high, particularly among soft woods.

When the shovel is working, it will often be found that a pole or two under the front, or where the lifting of the load is done, will suffice to support it. With worse conditions, more cross poles and outrigger poles should be used.

If long poles are not available, short ones may be used, centered under each track, but they are not nearly as satisfactory. There is a danger that they might tip under the shovel and jam into the machinery.

WET DIGGING

In any extensive wet digging, draining or surface pumping is liable to leave a sheet of at least a few inches of water on the bottom. This is a convenience in establishing a flat bottom grade, but, unless special precautions are taken, large quantities of water will be dug out along with the soil.

This water may run directly back into the hole, in which case the time and fuel used in lifting it is wasted. If it mixes with soil, either in the bucket or in the pile, it will tend to liquefy it so that the spoil will not stand in the high, steep sided piles which afford maximum dragline production with each stand. Piles with high water content are subject to flowing or slumping while being built, and may move back into the excavation afterward.

The spoil may come out as soft mud even if no separate water is included, but mixing of water will make it more sloppy.

Compartments. Shallow bottom water may be largely kept out of the bucket by compartment digging, as illustrated in Figure 3-16. A ridge is left between the digging and the water until bottom grade is reached. The ridge is then dug out and water allowed to flow in. Some mud will be washed onto the digging surface by inflowing water and by the removal of the ridge. Compartments may be large or small.

This method gives water-free digging for the bulk of the excavation, and can be used, with diminishing efficiency, in increasing depths of water, but not when the whole digging area is under water, as in deepening an undrained pond.

If little surface water is present, but ground water drains into the excavation rapidly enough to be a nuisance, digging can be in two or more compartments. First, the whole area is dug in layers until it gets sloppy, after which the digging is concentrated in one spot until most of the water flows into the hole made. An adjoining area, separated by a ridge, is then dug deeper and the ridge cut.

The water will now flow into the deeper hole, leaving the first one nearly dry and ready to be deepened in its turn. This alternation of digging spots can be continued to the bottom of the cut. If the area is too large to be dug in this manner, the water can be concentrated in gouges dug behind the regular layer cut.

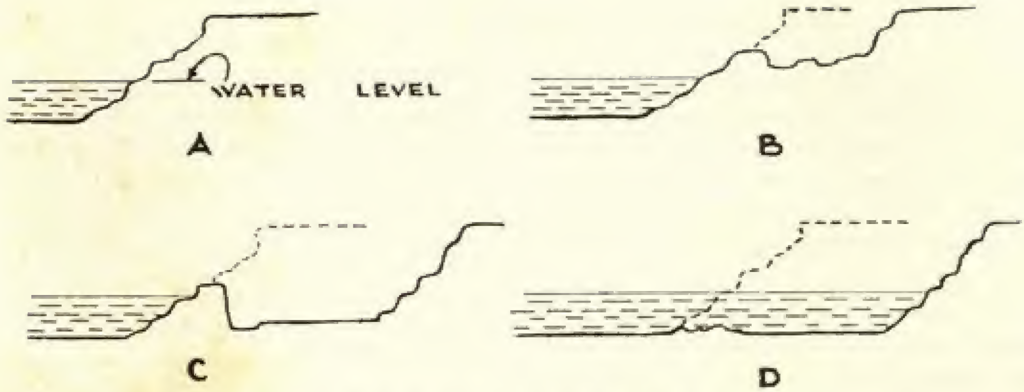


Fig. 3-16. Compartment digging

Spoil. If enough dry or stiff dirt can be dug to build a dike along the excavation edge of the proposed spoil pile, as in Figure 3-17, it will prevent mud behind it from flowing into the hole. There is usually ample space behind the pile so that the mud which moves in that direction makes place for more in the pile, and increases the amount of digging that can be done from one stand. The effectiveness of the dike will of course depend on the quantity and type of dirt available for it.

If the dirt is being loaded in trucks, an effort should be made to get dry material on the bottom to reduce trouble with the load sticking in the body.

Cable Excavators. Most excavating in swamps and mud is done by revolving shovels with dragline attachments. However, when the dug material is to be moved a great distance, or the amount is very large, cable excavators may be used. Since they can be anchored on one side of the swamp and operated from the other, they eliminate many of the difficulties and dangers of swamp digging. However, the work involved in setting them up and moving them, and the need for other equipment to remove the spoil from the tower foot, discourages their use except for large or long term operations, or where the digging cannot be done by any other available equipment.

Bulldozers. Bulldozers are not suited to mud excavation since they cannot work efficiently on artificial supports. However, they can skim shallow layers of mud off hardpan and dig cautiously in muds compact enough to give them some traction. In skimming work, it is usually best to start at one side of the mud area and make a pass removing the mud cleanly. Each successive pass should be to full depth and cut just enough into the side of the muck to fill the blade, without allowing it to slop off the other side of the blade into the cleared area. The mud should be pushed far back as the dozer cannot climb up on it to make high piles, and there is danger of its flowing back into the hole.

Wide gauge dozers are preferred, as they usually have wider track shoes for greater flotation, their weight is spread over a larger area, and they turn more readily on poor footing.

Cleats. Smooth or semi-grouser tracks are unsatisfactory as they have little traction on wet slippery surfaces. In general, tracks

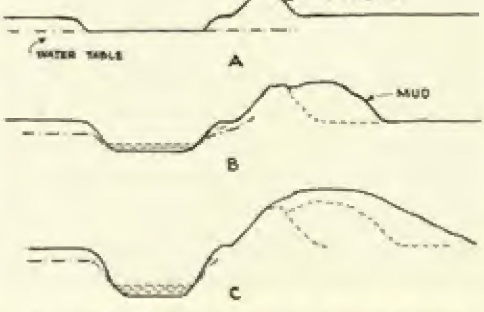


Fig. 3-17. Dike method of piling mud

with new and high grousers are better than those which are worn and rounded. However, such grousers on loose soil will dig in very rapidly, and many muds will pack in between them to make a new smooth surface even with their edges so that they become ineffective.

The best solution for straight mud work where rocks or very hard subsoils are not involved is to use flat shoes, with high grousers bolted on every fourth to sixth one. This should put two cleats on each track under the machine at all times, and will give a good grip which will not clog.

A similar effect can be obtained by building up some of the cleats on a set of standard track shoes, or replacing some shoes of a worn set with new ones.

A machine with cleats of variable lengths is likely to be almost incapable of working or traveling on hard ground.

Dragline Road Cut. A permanent road should not be built over unstable mud unless absolutely necessary. Such muds, particularly if rich in organic matter, will gradually be compressed and displaced by the weight of the road, allowing it to sink unevenly. The mud should therefore be removed down to firm bottom and replaced with clean fill if possible. If it is too deep, or otherwise too difficult to move, measures must be taken to stabilize it.

Shallow mud may be removed by a dragline working just ahead of the fill, and piling it to the side. The rate at which the mud pushes back into the hole determines how far ahead the dragline can be operated. A foot or two of mud liquefied by the mixing action of the shovel bucket is usually pushed out by the weight of the fill, but sliding in of the banks must be avoided.

Surface water should be diverted and sufficient pumps used to keep the hole fairly dry. This enables the dragline operator to see to clean the mud out thoroughly without unnecessary digging of firm soil, and will prevent the fill from being turned

SPECIFICATIONS FOR SINGLE-LINE COLUMN LOADS

CARTRIDGES PER HOLE	DEPTH TO TOP OF CHARGE	DEPTH OF DITCH	TOP WIDTH OF DITCH	DISTANCE BETWEEN HOLES	POUNDS PER 100'
½	6 - 8"	1½ - 2'	4 - 5'	12"	25
1	6 - 12"	2½ - 3'	6'	15"	40
2	6 - 12"	3 - 3½'	8'	18"	67
3	6 - 12"	4 - 4½'	10'	21"	86
4	6 - 12"	5 - 5½'	13'	24"	100
5	6 - 12"	6 - 6½'	16'	24"	125

CROSS-SECTION LOADING METHOD

CARTRIDGES PER HOLE	DISTANCE BETWEEN HOLES	DISTANCE BETWEEN ROWS	DEPTH OF DITCH
1	15"	30"	2½ - 3'
2	18"	36"	3 - 3½'
3	21"	42"	4 - 4½'
4	24"	48"	5 - 5½'
5	24"	48"	6 - 6½'

SPECIFICATIONS FOR POST-HOLE LOADING

No. of sticks (1¼ x 8") per hole	6	10	20	30	50	100
No. of lbs. per hole	3	5	10	15	25	50
Distance between holes - ft.	3	3½	4	4½	5	6
Depth of ditch "A" - ft.	4	5	6	7	8½	12
Bottom width of ditch "A" - ft.	4	5	6	7	8½	12
Top width of ditch "3A" - ft.	12	15	18	21	25½	36
Depth of load (⅔ of "A") - ft.	2⅔	3⅓	4	4⅔	5⅔	8
Diameter of post-hole - in.	4	4	6	6	8	8
Dynamite per 100 ft - lbs.	100	142¾	250	333	500	833
Material moved per 100 ft - cu. yds.	118	185	266	363	533	1,067

Fig. 3-18. Tables for mud blasting

to mud as it slides down the front of the slope. If the fill is too wide for the dragline to clear, it may be built out in sections.

MUD BLASTING FOR FILL SETTLEMENT

If the mud is too deep for available draglines to handle, or if it slumps into the excavation before fill can be placed, or if there is no adequate equipment to keep the water out, blasting may be resorted to.

Mud is easily blasted out of a limited area and spreads in a thin film over the landscape, leaving no heaps to dispose of. If a nitroglycerin or other sensitive dynamite is used, the concussion from one explosion may detonate other charges of dynamite in the mud nearby, without the necessity of using additional caps. The process, called propagation, greatly simplifies mud blasting.

There are three principal techniques: One is to blast a ditch along the right of way then dump fill in it. Another is to

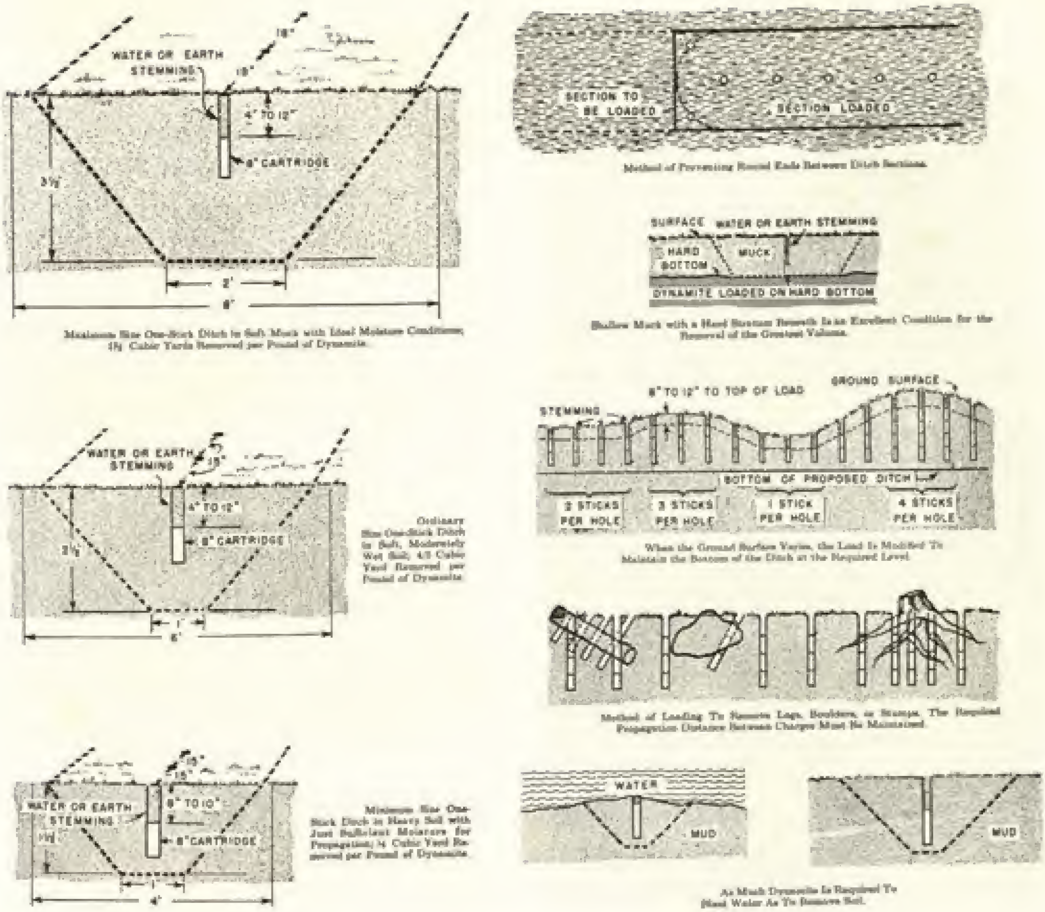


Fig. 3-19. Loading for ditch blast

build the road, or a section of it, on top of the swamp and blast the muck from under it. The third, toe-shooting, consists of making a big heap of fill and blasting the mud ahead and to the sides from under that.

Ditch Shooting. The tables in Figure 3-18 give average loading requirements for various types of open ditch blasts. Figure 3-19 shows how to load for rather narrow ditches, which are used chiefly for drainage, or to make possible placing of an earth dike to cut off movement of water or mud. It will be noted that the nature of the mud is very important in determining the size ditch which will be obtained from a given charge.

It should also be remembered that water counts as soil in loading calculations.

Blasting techniques for wider ditches, which are used to remove muck to secure a firmer base for road fills, are indicated in

Fig. 3-20. Cross-section loading

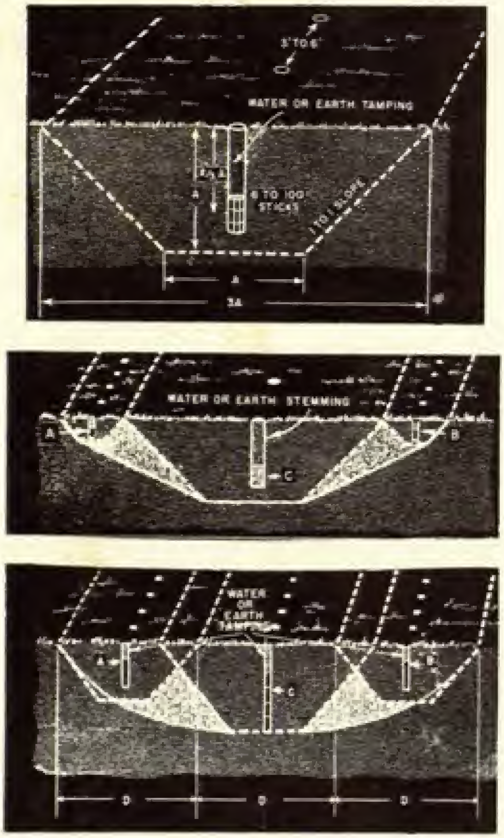


Fig. 3-21. Post hole and relief loading

Figures 3-20 and 3-21, which show the cross section and relief methods.

The charges should be 50% or 60% straight dynamite, at least 4″ below the surface, and covered with mud or water. The blasting cap should be in a stick of dynamite at or near the center of the group to be blasted, and with the loads and distances shown in the illustrations, should detonate them all.

However, if the structure of the muck changes between holes, it may shear, and direct the force of the concussion upward or to the side, and charges beyond that point will not explode. In this case, one of the remaining charges should be lifted and primed with a cap, or an additional primed stick should be placed and detonated.

If many reprimings are necessary, it may be better to put a cap in each hole and explode them simultaneously by electricity. As a great many caps are generally used in a single blast of this type, a powerful jolt of electricity is needed.

It is not usually necessary to remove stumps and brush from an area to be ditched by explosives, but trees should be cut and the trunks removed if possible. Extra charges should be placed under stumps, and an effort should be made to get them to throw toward the nearest edge of the ditch. If the stumps are so heavy or so numerous that they prevent accurate ditch work, they may be removed first by draglines, winches, or other machinery, perhaps with some blasting to loosen them up.

The dynamite will probably not remove all the mud down to hardpan, but it may liquefy most or all of that which remains, so that the fresh fill will sink through it to firm bottom.

Underfill Shooting. Figure 3-22 shows the second method. Brush, stumps, logs, and other debris are removed from the right of way, and any heavy sod or brush broken up by machinery or light blasting. Fill is placed in an amount calculated to reach from firm bottom up to the desired road grade. Charges are placed in the mud in casings driven through the fill. Shooting is by Primacord, or by caps in each hole, rather than by propagation.

The mud explosion is confined by the mass of fill above, and should blow out the sides, driving out most of the mud and liquefying the remainder so that the fill will sink to hardpan.

If the fill is clay or other compact material that might tend to bridge over the blasted cavity instead of settling in it; or if the weight is not considered to be sufficient to resist the explosion, deep ditches may be blasted on each side of the fill after it has been placed and the charge

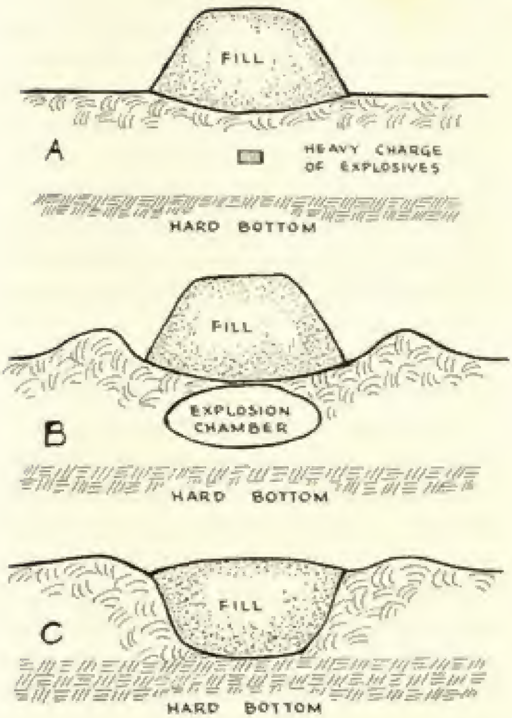


Fig. 3-22. Bottom shooting

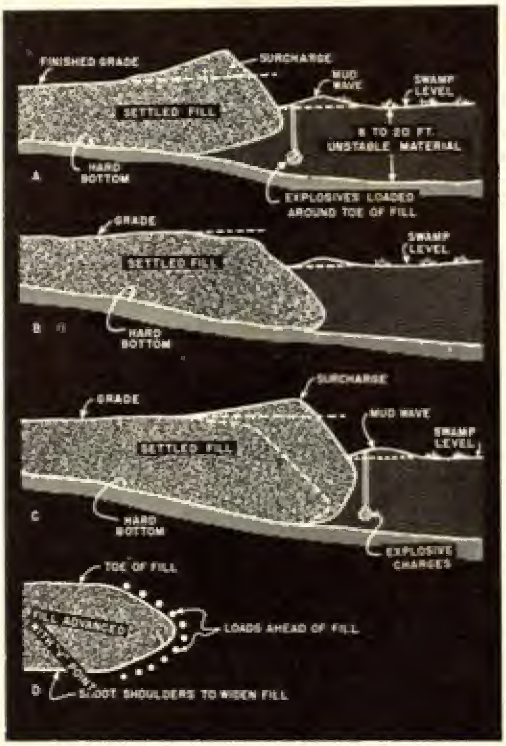


Fig. 3-23. Toe shooting

set off under it afterward. Blasting these relief ditches makes it much easier for the explosion to drive the mud from under the fill, but it also puts a thick layer of muck on top of it, which must be bladed off.

The charges under the fill must be so placed that there will be no danger of them going off by propagation. 30 or 40 per cent gelatin is recommended.

Toe Shooting. Toe shooting is illustrated in Figure 3-23. This is the second method —fill, then blast—done in such short sections that the muck will be driven out to the front as well as to the sides. It has the advantage of allowing the blaster to have frequent checks on the efficiency of his work, so that techniques of loading or filling may be altered readily. A disadvantage is that the muck blown ahead sometimes piles up in a large hill or wave of mud, making continually larger charges necessary to move it. This tendency may be reduced by making the fill with a V-shaped front so that most of the material will be thrown to the sides. The mud wave may be blasted away in separate operations, but part of it will then have to be cleaned off the fill.

Toe shooting is an excellent method to widen fills, the extra material being piled on the sides and a single line of charges set off in the mud underneath.

Placing Explosives. Shallow placement of explosives in mud may be made by pushing them down with a stick, or first punching a hole with a crowbar, then using the stick. For deeper work the apparatus shown in Figure 3-24 is effective. A plain piece of iron pipe of the necessary length is used for a casing, and a round wood pole or a plugged iron pipe making a loose fit serves as a core. The core is set in an iron handle larger than the casing and long enough for a good two-handed grip.

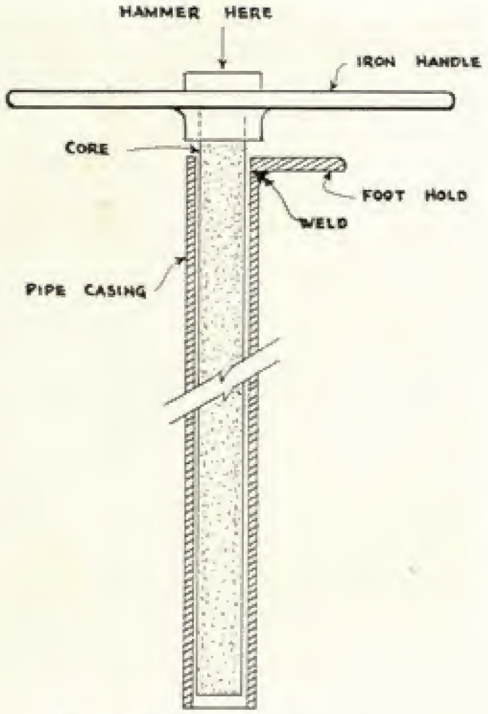


Fig. 3-24. Cartridge-placing tool

The core is placed in the casing and the two pushed or hammered down into the mud by means of the handle. The core is withdrawn, the casing being held down if necessary by a foot on a bump welded on the side. The charge may then be dropped down in the casing, or pushed down by a long wood tamping stick, the same diameter as the core. This stick is used to hold the charge down while the casing is pulled out. Difficulties experienced will increase with the size and length of the pipe, and it may be necessary to use chain jacks or hoists to pull the casing.

Space permits only this brief summary of mud blasting techniques. Further information may be obtained in other parts of this volume, and from various books and bulletins dealing with explosives, but it is advisable to have an experienced mud blaster on any important job.

Results. A fault of all mud removal techniques mentioned is that they require placing a considerable depth of fill in a single layer so that it cannot be properly compacted; or the fill is shaken up by blasting and sinking after being placed. This is liable to cause uneven settlement, and in addition there is the danger of pockets or layers of muck getting included in the fill, due to miscalculation, or partial failure of blasts, or rapid slumping after excavation. However, the stability of the fill will always be greater than if it were simply laid on top of the swamp.

STABILIZATION

Dewatering. One method offers stability equal to that obtained in normal, dry fills, but at high cost. The right of way can be dried up by draining, or well point or sump pumping, as described under Ditching and Drainage, then excavated to firm bottom with machinery. Fill may then be built up to road grade in thin, thoroughly compacted layers and with properly sloped sides. When it is complete, pumping may be discontinued and the muck allowed to settle back against the slopes.

Removal of muck in any way is expensive work, except in the rare cases where it can be sold locally for humus. The expense increases very rapidly with depth, and a point will be reached where it is good practice to stabilize the mud rather than remove it. This is particularly true if the area involved is wide, or conditions do not permit side casting or blasting.

Sand Drains. Muck can be stabilized if enough water can be squeezed out of it to convert it from a semi-liquid into a solid. The weight of a heavy road fill has a squeezing effect, but the mud and water flow together and very little compaction is obtained for a long time.

Vertical sand drains may be used to dry up the mud so that it will support a load. They consist of columns of sand extending from hard bottom to the top of the mud, and connected at the top to each other, and to an outlet by a sheet of sand or gravel,

or other drainage systems. They are discussed in Chapter 5.

Chemicals. If digging is done in a water bearing sand or gravel, very soft conditions and extensive caving of banks may be experienced. This difficulty may be avoided by drying the area with well points, or by other methods described in Chapter 5, but if the inflow of water is very large, or the excavation must be opened for an extended period, it may be more economical to wall off the water by use of chemicals.

If sufficient cement grout is pumped into a porous soil, it will displace the water, and when it hardens, will block the spaces which the water occupied. The success of this work depends on the nature of the soil and the skill of the grouting crew.

Grouting is best done before digging, or after allowing the excavation to fill to the ground water level, as this will prevent heavy losses of grout in flowing water, and permit use of a thin mixture with good penetrating qualities.

Methods of injecting the grout are discussed in Chapter 6.

Other chemicals may be used to harden soils too fine grained to respond well to grout, but these, and the methods of using them, are now largely experimental, or are unsuitable for application by unskilled personnel.

Freezing. Any soil in which pipes may be sunk can be stabilized by freezing, but the presence of salt, or certain other chemicals, may make it difficult.

It is accomplished by sinking a number of metal pipes, rather closely spaced, in the area to be stabilized. Tubing containing a refrigerant, usually ammonia, is placed in these pipes and connected to heavy-duty refrigerating apparatus. The soil water will freeze most rapidly if it is stagnant, but even a steady flow can be checked.

This is an expensive job, mostly confined to very fine grained mud, or deep work which does not respond to well points.

FILLS

Compaction. In fresh fills the most serious mud difficulties are due to improper compaction. Here it is sufficient to say excellent compaction may be obtained if a fill is made in layers six to eighteen inches in depth, and each layer is thoroughly rolled or tamped in all parts. If rollers are not available, trucks may be used, first empty and then loaded. Such a fill usually will be incapable of absorbing enough water to turn to deep mud. The extra expense and nuisance of making a fill in this manner, when specifications do not call for it, may be regarded as an insurance premium against the loss of having to stop a job for days or weeks because of a soft dump. The expense may be not only the extra dozing required to spread, and the roller or machine time to compact, but the fact that from 10 to 40 per cent more material might be required to fill the same hole.

Under many conditions, such as stumps and boulders in fill, rough or liquid original grade, poor access or insufficient machinery, deep single layer fills are unavoidable. If the top is properly compacted by rollers or traffic it may suffice to shed rain water, and to resist water soaking up from below. Areas receiving no compaction except from grading of the fill by a light-footed dozer, are liable to soak water up like a sponge, and be a hopeless quagmire for a while, and also tend to wet and soften surface compacted areas.

Clay. Clay fills are liable to become soft and slippery during rain. The wet surface may be bulldozed off and replaced with dry material, or the dry material may be dumped over the mud in sufficient quantity to carry traffic over it, and be removed later. If rain is anticipated, the original fill may be left low to leave room to cover it.

If fill is coming from two or more sources, it is sometimes possible to keep the clay in lower parts of the fill and better material on the top.

Area Dumping. If trucked soil is too wet to be stabilized and will not support trucks after being spread, and if the ground (or lower layer of the fill) is passable to trucks, area dumping may be resorted to. A calculation is made of the amount of fill needed in a given area, and the amount of each incoming load. Allowance must be made for shrinkage of the soil upon drying and after compaction, and the number of loads required in such an area may be found by dividing the cubic yards required by the corrected yardage of a truckload.

The trucks may then dump their loads in piles which can be left to dry, then be spread and compacted. The easiest way to figure pile spacing is from center to center.

If more material is needed than can be left by dumping piles, higher bodied trucks may be hired, or a bulldozer employed to push the newest piles into and over the older ones.

Fill dumped in this manner is seldom in just the right quantity in the right place, but it can be shifted around during the grading process.

Buried Mud. If it is impossible to truck in the area to be filled, the mud must be covered as it is dumped with a layer of dry fill, gravel, or rock sufficient to support the trucks. Sometimes the mud will support a bulldozer which can roughly grade the soft fill. The dry surfacing is advanced close behind the face of the mud fill, trucks dump the mud at its edge, and the dozer pushes it over the face, digging down sufficiently to allow placement of more surfacing. See Figure 3-25.

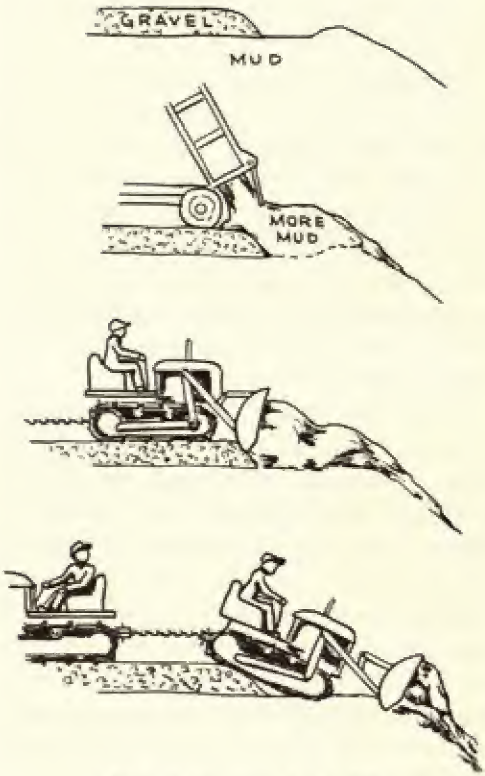


Fig. 3-25. Two-layer fill

In such mud work, it is advisable to have at least two dozers, so that the one working in mud can be promptly rescued if stuck. Under extreme conditions two dozers may be attached to each other, back to back, by a chain or cable. As one of them pushes mud toward the face, the other backs up toward it, keeping the line slack. When the pusher backs up, the other one pulls it to firm footing. The helper cat need not have a dozer, and preferably should be larger than the one doing the work. Wide tracks are a big asset in mud.

STUCK MACHINERY

The next problem to consider is how to rescue machinery that has sunk so far into mud that it cannot move under its own power. The easiest and most attractive method is to stretch a chain or cable to some power source and pull it out. Often there is no such power available, but if there is it should be used with caution. If the stuck machine has not sunk, but has simply lost traction on a slippery surface,

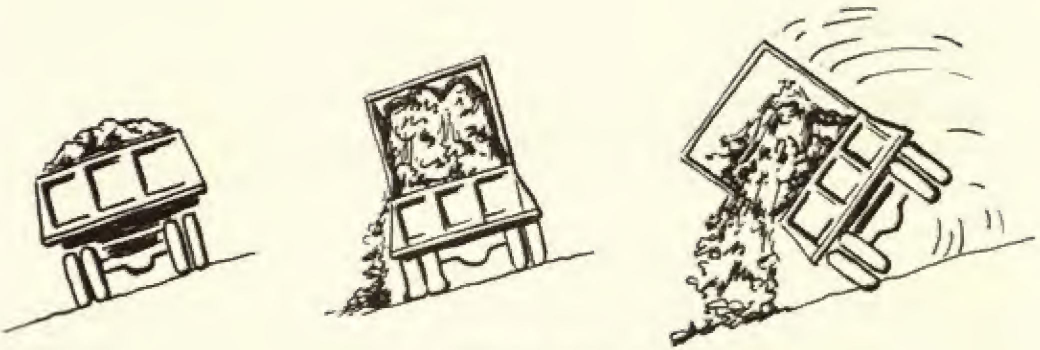


Fig. 3-26. Dumping on a side slope

power can usually be applied without damage. However, if it is in badly, use of moderate power may be useless, and too much power may pull it apart.

TRUCKS

Dump trucks are probably the most frequently stuck type of equipment. If one is loaded, it may be possible and desirable to dump the load, after which the truck may pull out under its own power. But if the truck is tipped sideways, as with one pair of rear wheels bogged down, the other resting on the surface, the raising of the load preparatory to dumping increases the sideward strain, and may overturn the truck or tear the body off its base. A winch cable attached to the front top of the body on the high side, and pulling uphill, may permit dumping of a tipped truck, but even with skillful operation, the strain on the body is considerable. Unloading by hand, or partial unloading by power shovel, may be necessary.

A shovel is a highly effective rescuer of bogged trucks. A dipper bucket may be placed under the rear of the frame (or, with some risk of damage, under the rear of the body) and lift and push at the same time. Other shovel attachments may have the bucket chained to the truck to lift or drag it, or the shovel may be used as a tractor for a horizontal pull. Hand digging is rarely necessary if a shovel is available. Pull-type shovel rigs can remove most of the load but cannot push very effectively.

Digging Out. If the truck cannot be dumped, or has been dumped and is still stuck, and no power shovel is at hand, the next procedure is to dig out the wheels in the direction toward which it is hoped to move. Two-wheel drive trucks have best traction going forward, and in many situations, such as sinking in a soft shoulder, an attempt to back out will cause the front wheels to get in worse difficulties. Any digging helps, but the best procedure is to go to the bottom of all tires, make a ramp up to the surface with a length of three or more feet to every foot of depth, and put a board or boards on this slope, with the lower end against or under the tire. If boards are not available, matted brush,

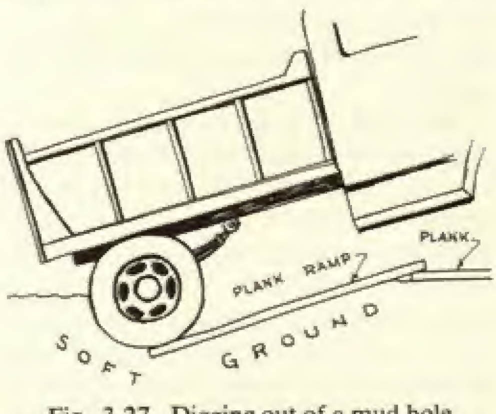


Fig. 3-27. Digging out of a mud hole

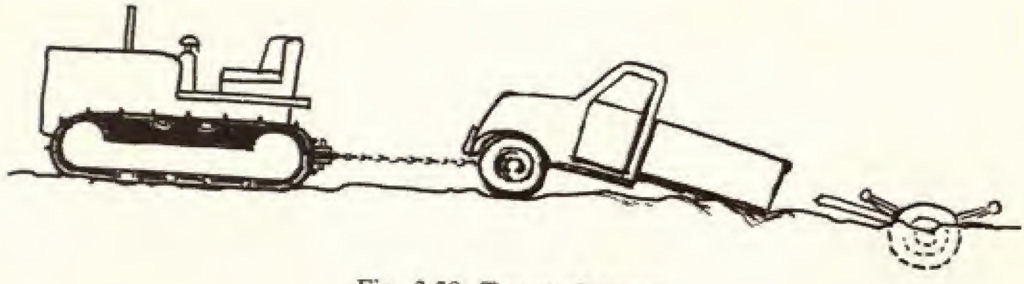


Fig. 3-28. Too much power

stones, gravel, or anything but mud may be used. If the axles or frame are resting on the ground, an attempt should be made to free them, but this is often not possible.

Even if this digging does not enable the truck to get itself out, it makes it much easier for a light machine to pull it, and it greatly reduces the danger of damage if pulled by a large machine.

Breakage. Applying brute force to pulling a deeply bogged truck may result in getting it out minus its rear axle assembly and wheels, a partial victory that brings little satisfaction. In most trucks the rear axle is attached to the frame only by the spring shackles and propeller shaft.

Lesser and more common damages are tearing off of bumpers and bending of front axles. Many trucks have no satisfactory pull points on the front end. The bumper should be used only at the fastening to the frame. If it is necessary to use the axle, the line should be attached as close to a spring as possible, and care should be used to prevent it from catching any part of the steering when tightened, or when the wheels are turned.

Pull Line. The most generally effective device for extricating bogged machinery is a winch. It may be mounted on and powered by a tractor or a truck, or be a portable affair. A power winch may have 200 or more feet of cable which enables it to reach a long way from firm ground, or on shorter pulls, to multiply its power many times by means of pulleys and anchors. The procedure for rigging and operating the winch is the same as that described under stump pulling in Chapter 1. The use of multiple lines is often advisable, even when the machine may be de-bogged by direct pull, as the slower speed is less liable to cause damage. Hand winches are slow and laborious to wind in, but are powerful and can be used in places inaccessible to larger machines.

Where possible, it is best to pull the truck straight out with the truck wheels driving. If it is necessary to pull at an angle, the truck should be steered toward the pull.

A cable or chain may be stretched from the stuck truck to another truck or a tractor, with or without pulleys, and a traction pull used. Care should be exercised not to use too short a line and get the assisting machine stuck also.

Push. A bulldozer equipped tractor can get behind it to lift and shove at the same time, but a man should be stationed to put poles in front of it as it moves so that it will not get stuck in the hole the truck leaves.

Body Hoist. A dump body usually extends a short distance behind its hinge, so that when the body is raised the rear edge of it goes down a few inches. Advantage may be taken of this feature by chaining the axle tightly to the frame, perhaps lifting it first by chaining it to the front of the body and hoisting; placing a plank on the ground under the rear of the body, and fitting a stout log between plank and body. If the body can be raised, the rear edge

will push down against the log to lift the frame, and through the chain, the axle and wheels. Axle or wheels can then be blocked up, the body lowered, and the log shimmed up to meet the body at its new height, and the process repeated until the wheels are high enough so that a support or ramp can be put under them. See Figure 3-29.

Jacking. If a heavy jack is available, the axle may be chained to the frame, the jack placed on a plank or other support, and frame and wheels raised and blocked in the same manner as when the body lift is used. If it is not possible to chain the axle to the frame first raise the frame with jack or body hoist, then jack the wheels up with a light jack based on a board and placed under the wheel rim or hub.

Wheel Tractors. A wheel tractor in mud presents a problem similar to that of the truck, except that because of the large size of the rear wheels, and the solid fastening of rear axle housing to transmission, there is less danger of pulling it apart. If the tractor is equipped with a loader, the bucket may be chained or weighted down so that the lift will raise the rear wheels out of the mud. Supports should be placed under the front of the tracks so that they will not sink instead.

If a truck or wheel tractor is stuck more because of slippery surface than sinking, tire chains, short chains threaded through wheel openings, or rope or rags tied around the tires will help to give traction.

Wheeled vehicles do best in mud or sand with large tires, or standard tires with reduced pressure. Truck tires break down rapidly if under-inflated, but tractor tires usually have thin flexible sidewalls and operate at such low speeds that they can run soft for considerable periods before being damaged. However, they may slip on the rim and tear out their valve stem if too soft.

Churning. A very important item in the sticking of vehicles is to know when to stop struggling. Often a minor tow job is changed into a major project by a driver continuing to spin his wheels and buck back and forth until he has sunk his vehicle completely. In rescue work, the strongest measures available should be applied early, as every attempt that fails is likely to make the job more difficult, and danger of damage to the sunk vehicle more severe.

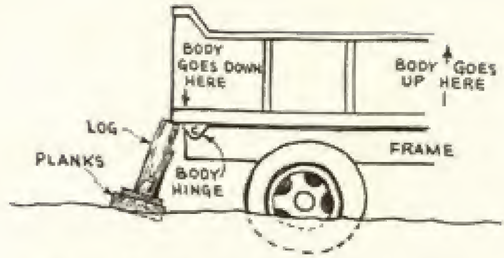


Fig. 3-29. Jacking out with body hoist

CRAWLER TRACTORS

Crawler machines do not bog down as readily as wheeled ones, but can do an even more thorough job of it.

A crawler tractor may sink in mud too soft to support it, or it may dig itself in while pulling a load, or both. If the tracks are allowed to spin, the grousers act like buckets on a ditcher, digging soil from underneath and piling it behind. On soft ground they can work down rapidly this way, until the frame parts of the tractor are resting on the ground, or on a stump or other object its normal clearance would have taken it over. When the weight of the tractor rests thus on the frame, the tracks churn helplessly in air or loose mud.

Pulling Out. If outside power is available, the machine may be pulled out by a line attached to its drawbar, front pull hook, or other hold. It should be pulled straight forward or backward, if possible, with its own power being used also. The drawbar, or a bulldozer blade, can sustain a terrific pull without damage to itself or the tractor, but front pull hooks should be used with caution. They are usually bolted

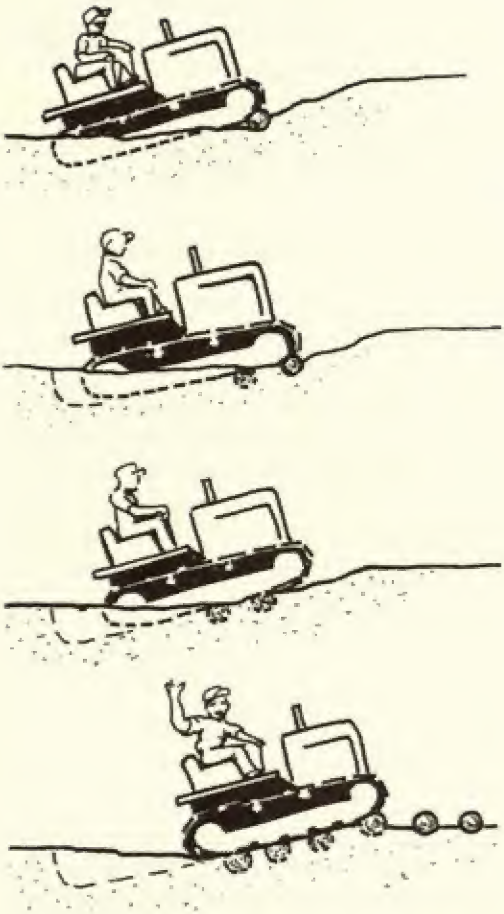


Fig. 3-30. Walking out on cross poles

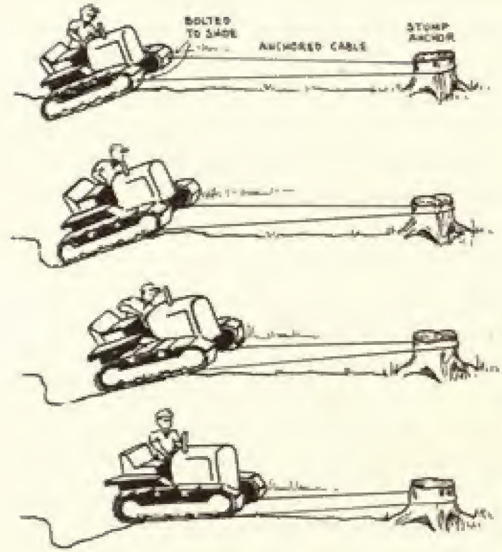


Fig. 3-31. Climbing a cable ramp

to the crankcase guard, which may be attached only through the flywheel housing to the rest of the tractor. A heavy pull on such a hook, particularly at an angle, is liable to break the flywheel housing and pull the engine out of the tractor. Sometimes the housing will partly break as the tractor comes out of the mud, vibration and rough footing will cause the break to expand, and the clutch will fail or the engine fall out of the tractor days or weeks later, to the bewilderment of everyone concerned.

Poling Out. If no outside power is available, and the stuck cat has no dozer, winch, or other helpful equipment, the first thing to try is digging a shallow ditch in front of (or behind) the tracks, a foot or two wider than the tractor. In this put a green sapling or strong board as long as the ditch, pressing or wedging it tightly against the tracks, which should then be turned slowly so as to pull the stick underneath. When it is well under, press in another stick, and perhaps more. Their effect will be to lift the tractor and restore the weight to the tracks, provide a wide base for support and traction, and to cut off or uproot obstacles under the tractor. They are almost certain to get the machine out if it will pull them under.

If the tractor has flat shoes or grousers that will not grip the size of pole available, and no bolt-on cleats can be obtained, or if there is an aversion to digging ditches, planks or heavy angle irons may be drilled and bolted to track shoes on both sides. The effect is then positive, but it is very necessary to unbolt and remove them as they come up at the other end. Poles or logs may be fastened to the shoes by loops of cable and used in the same manner. Short sticks should not be used unless absolutely

necessary, as they do not afford nearly as much lift or traction as long ones, and they are liable to turn underneath and jam things.

These stratagems are equally effective at moving the tractor forward or backward, but reverse gear often has less power than low, and backward movement under difficult conditions is a severe strain on the tracks.

Cable Ramps. Another system is to fasten a cable to each track, or the two ends of a single cable to the tracks, perhaps by passing it from the outside through a hole in the shoe, and catching it inside with a loop and clamps. These cables should be stretched parallel or nearly so straight ahead of the machine to anchors of some sort. When the tracks are turned to move forward, they will advance on top of the cables, which will prevent them from spinning and provide a tightrope ramp on which they can climb. This technique should be used with caution in reverse as the strain on the track may break it. See Figure 3-31.

Chains may be bolted to the track and used instead of cables, but they are much heavier for the same strength and are seldom long enough for the job.

The tractor may also be jacked up on planks, in the same manner as a truck, and the hole filled in or bridged.

Winching Out. If the tractor is equipped with a towing winch, the cable may be fastened to an anchor behind it, and the machine will come out of the mud as the cable winds in. This should be done with caution if the presence of a stump or large stone underneath is suspected, as it might force a track off, or do some other damage. Risk can be reduced by putting blocks behind the tracks so that it will move up as well as back, or by anchoring the cable at a height, as in a large tree.

If the tractor is too badly bogged to turn, the only available anchor is not directly in line, and the winch is of a type that the

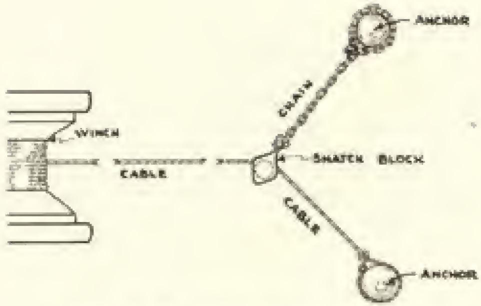


Fig. 3-32. Changing angle of pull

cable runs off the spool on an angle pull, run the cable out until it is slack then hold it with a crowbar or stick so that it reels on the side of the spool opposite to the direction of the anchor. When the pull begins, it will be off center and will have a tendency to turn the tractor in line with the anchor. If it does not do this, it will wind onto the drum in a spiral, making one or more loops before reaching the edge on the anchor side, moving the tractor a short distance. The line can then be slacked and the procedure repeated.

If the angle between tractor direction and anchor is too great, a second anchor must be used and a chain from that adjusted to hold the cable in line. Use of a snatch or pulley block, as shown in Figure 3-32, will prevent damage to the cable from the chain hook. If alignment is satisfactory but the winch does not have enough power to de-bog the machine, a pulley may be chained to the anchor and the winch line passed around that and back to the tractor drawbar. This will nearly double the pull.

Dozer Down Pressure. If the tractor is equipped with a hydraulic bulldozer, but no winch, the blade should be raised; planks, poles or other floats placed, dug or driven under it, and down pressure applied to the blade. If the hydraulic system is in good condition, this will raise the front of the tracks clear of the mud. Poles may then

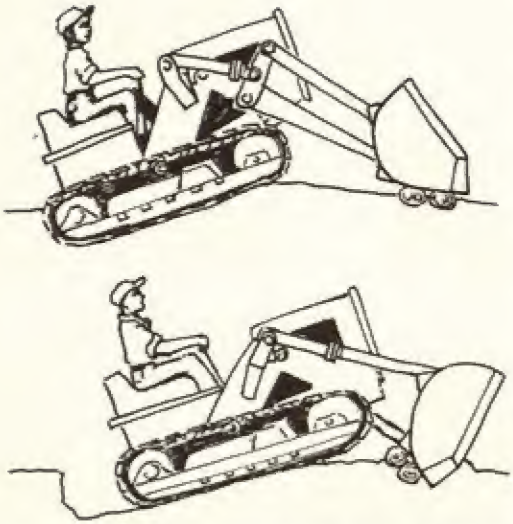


Fig. 3-33. Pulling dozer shovel out with bucket

be forced under the tracks, or the holes filled with rocks, and the tractor can walk out after raising the blade. If the dozer will not raise the tractor, and there is enough oil in the system, try letting the machine cool off, as a worn pump will develop better pressure on thick, cold oil. If it still will not work, or if there is no time to wait, proceed as suggested for a plain tractor.

Cable Dozer. If a tractor equipped with a cable bulldozer is stuck, and plenty of pulleys and extra cable are available, the blade might be supported by a chain, and the control drum rigged to pull it out. The heavy pull of multiple lines should be through the drawbar or blade.

Dozer Shovel. Dozer shovels equipped with flat or semi-grouser shoes get stuck easily in wet holes. A hydraulic dump bucket can be used to get one out by holding it on the ground in the flat position, and dumping it at the same time that the tractor tries to walk forward. The bucket edge grips the soil, and its backward movement pulls the tractor. When the bucket reaches the fully dumped position, the tractor is held with its brakes, and the bucket raised and flattened for another pull. The ground under the bucket can be reinforced with poles, as in Figure 3-33.

If the tractor must back to get out, the bucket is placed in the ground in dumped position and moved toward flat. The bucket can also be used in this manner to move a tractor which cannot walk because of a defective clutch or other breakdown which does not lock the tracks.

The front of the tracks can be raised off the ground by using down pressure with the bucket floor vertical, and supported by poles or blocks. The rear can be raised by shoring up the front and piling the bucket with heavy material.

Hanging Up. Tractors are frequently hung up on stumps or rocks in the absence of any mud at all, usually through digging in the tracks while moving a heavy load. The first warning is liable to be a failure of the tractor to keep its direction or to steer. The tractor should be stopped immediately and the situation checked over. If the stump (or rock) is under the crankcase guard or other smooth surface, the tractor may escape by backing or turning, or by climbing a rock or a stick placed under one track. If the obstacle has wedged into a hole or raised section, large rocks or logs under the tracks, or even jacking, may be required to get free.

A crawler tractor may also be hung up by walking over a large flat stone or short log which flips up and catches in the chassis or between the tracks. This situation deserves careful examination before working, as applying too much power in the wrong direction may break a track or do other damage. Movement in the right direction, particularly turning one track only, may free it; or climbing up on blocks or using another power source to pull the rock out the same way it went in. Sterner measures are removing the track, or turning the machine on its side in order to break up the stone, or to chop the log.

Overturning. If a crawler tractor is ly-

ing on its side, it may be rolled back on its tracks by pull on a line fastened to the highest substantial structure near the center of the up side. If there is no spot above the center of gravity which will take the pull the line should be run across the up side and what is usually the top of the tractor until a hold is found. Logs or other blocks under the line should be used to protect the tractor parts against crushing. An improvement on this is to use a pulley in a tree, or in a heavy tripod, so that the line will lift as well as pull.

If the machine is upside down two pulls may be necessary, one to get it on its side, the other to right it. This is easiest downhill, but blocks must be arranged to prevent it from rolling farther than planned. Power should be applied slowly to avoid bending or crushing of parts.

If no power is available, hand jacks should be obtained together with planks and blocks. A jack placed on a plank should be used to raise some portion of the tractor, blocks placed to hold it at that height, the jack released, blocks placed under the jack, and the process repeated. One jack will do it, but two are easier. It is good procedure to start jacking the part of the machine which will move the longest distance in resuming upright position, and work the jacks in as space opens up. If the cat is dozer equipped, the dozer frame and blade will safely take the strain of jacking. The dozer may sometimes be moved advantageously, using the starter for power.

The type of jack shown in Figure 3-34 is particularly useful in machine salvage.

SHOVELS

Planks. Power shovel tracks usually have flat shoes, so that it is difficult to get them to grip poles or planks and drag them under, without excessive trenching, or bolting or cabling them on. Before working a dragline or other shovel in risky places, it is a good plan to get a plank 2″ × 12″,

Fig. 3-34. Equipment salvage jack

3″ × 12″ or heavier, two feet longer than the shovel is wide, and drills holes in it to match the holes in the track shoes so it may be readily bolted, and carry it for use when necessary as described under tractor rescue. Strain on plank and shovel will be reduced by trenching deeply to the under slope of the idler if possible. If the

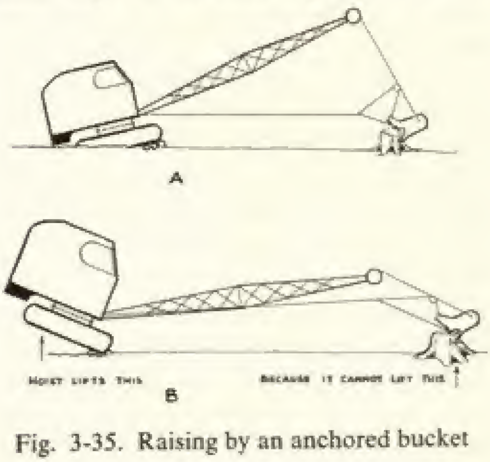


Fig. 3-35. Raising by an anchored bucket

shovel can climb up on this plank, saplings or other helps can be placed in front of it to assist it to firm footing.

Hoisting Bucket. If a dragline is down on one end, logs or planks can be forced or dug under the high end, and the low end raised by hooking the bucket or hoist cable to a stump or other anchor, as in Figure 3-35 (A) and (B). Pulling in the hoist cable, or raising the boom, should tip the shovel forward, lifting the rear sufficiently to allow shoring up with logs, as in (C).

If the anchor is close, a low boom gives best leverage. If it is distant, a high boom is better. However, a boom angle of over 45° may be dangerous, because if the hoist line breaks or comes off the anchor, the reaction might throw the boom back on the cab.

The same procedure can be used if one track is bogged and the other one is free.

If the shovel is down all around, trenches can be dug to permit bracing under one end. This is used as a pivot to raise the other end, which is then shored up. The boom is swung to an anchor on the opposite side and the hoisting and blocking repeated.

Two anchors may be chained together for greater strength, or to secure a better direction of pull.

If no anchors are located in the proper direction, and it is not practical to make one, the bucket can be used as counter-weight. The dump cable is shortened to permit holding a load far out. A bucketful of the heaviest dirt available is dug, the boom lowered so that the bucket can be held just above the ground. Rocks or weights are piled on the bucket until the shovel tips. If the rear of the tracks is not high enough, it can be brought up by raising the boom.

In any blocking work a loose track is a nuisance as it will hang down and impede placing of supports. The slack can be readily taken out by placing a jack on the track frame and raising the upper section.

Drum Line. A shovel can sometimes pull itself out of trouble by a line attached to one of its own drums, or to a drag bucket. These lines are too fast for a smooth, steady pull, and the drums are so high that there is a tendency to pull the front of the shovel down. Better results will therefore be obtained if the line is passed through a pulley chained to the anchor, and back to the bottom of the dead axle. If several pulleys are available, and all additional lines run to the dead axle, a very powerful, well directed pull will be obtained.

Jamming Chains. A special precaution to be observed with shovels is to keep the drive chains free from material of any kind. Stretching or jamming these with mud, gravel, or debris is not only a severe strain on the chain, but by increasing friction within the chain and with the sprockets absorbs a large part of the drive power needed at the tracks.

Straddling. It is risky to work a shovel that is straddling a stump or boulder, unless the ground is known to be entirely firm. The rhythm of load, swing, and rebound causes the tracks to work their way down into soft earth, particularly at the load end. If there is a thin layer of sod or hard soil overlying unstable material, the top will give an appearance of solidity, but if it breaks through, will let the machine sink rapidly. Ordinarily, slight sinking can be ignored or checked by poles under the tracks, but if it causes the shovel under parts to rest on a stump, it is a more ticklish situation.

The under parts of a shovel, between the dead axles, are more vulnerable to damage than any part under a tractor. In mud there is often nothing to do but to get out any way and hope for the best, but if possible, any projection reaching up into this vulnerable area should be carefully watched during rescue work.

The shovel may be freed from an obstruction by anchoring the bucket and

hoisting, or by walking it up on logs, or using a plank bolted to the tracks, or even by using a long crosscut saw to cut off a stump while still under it.

Counterbalancing. If a shovel sinks so far on one side that it is in danger of overturning, the boom should be swung to the high side and lowered as much as practicable, the bucket extended, and weighted or anchored, then raised to serve as a counterbalance. This should prevent further tipping and may make it possible to shore it up.

Overturning. If a shovel is overturned or so steeply tipped that it cannot be operated, the swing lock should be set, a line should be attached to the top of the A-frame and to any available anchor on the high side, and drawn taut to prevent further settling. If this line can be attached to a power source of sufficient strength, the shovel may be pulled upright, but this should be done slowly, with careful attention to any tendency toward bending the A-frame or other parts.

If no adequate power is available, a platform must be laid or constructed on the ground, and the shovel raised with jacks and blocks. The best and cheapest blocks are old railroad ties, but any sort of beams or heavy planking may be used. The actual raising of a shovel is so intricate, so dependent on the position and construction of the machine, and so liable to result in severe damage if done improperly that it cannot profitably be described here. The best method is to hire people who specialize in rigging and machine moving, work with them, and remember their methods.

If a shovel starts to tip during a swing, the bucket and load should be dropped, if possible.

Counterweight. If a shovel is heavily counterweighted to carry a long boom, and the boom is removed to install another attachment, the shovel has a tendency to turn over backwards. Removing counterweight is usually too much work to be practical. The shovel may be walked slowly to its other attachment, with a high heavy sawhorse or some other support dragged or pushed along under its tail. Or a line may be rigged from its A-frame to a tractor or heavy truck moving ahead, and kept taut, a device which can be used not only to steady it but to pull it upright if it does "sit down." Another system is to bring the attachment to the shovel.

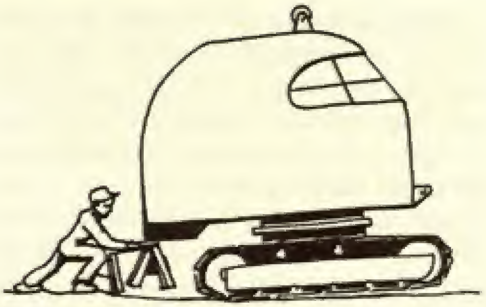


Fig. 3-36. A basic shovel is tail heavy

FREEZING DOWN

Frozen Mud. Mud may cause serious difficulty when it freezes, as it sets like concrete and anything in it is likely to stay there. Crawler machines are particularly vulnerable, for if they are muddy, tracks, track wheels, and chassis are liable to be combined into one immovable unit. If they are clean, they are still apt to freeze to the ground.

Precautions to be taken are to clean all mud from the tracks and wheels at the end of the shift, and to park the machine on rock, metal, or wood, with as much of the track length as possible in the air. Mud should be at least scraped off with a trowel, screwdriver, or stick, but it is safer to wash it with a hose also.

Frozen mud is hard, heat resistant, and tough, particularly when very cold. However, the bond between mud and other materials may be a film of brittle ice, which will resist pull or twist but shatter at a quick blow.

Breaking Loose. If the tracks are frozen down, but the track wheels are free, the machine can often be broken loose by rocking it forward and backward with clutch and gears. Jerky clutch action is much more effective than smooth, but also much harder on the machine. Moving forward tends to loosen the rear pad, backward the front. The hardest part of the job is getting the first crack in the frost, after that the additional movement makes the breaking away progressively easier. It is sometimes advantageous to apply power to one track at a time, using the steering clutch to disconnect the other.

If there is frozen mud holding the wheels, it is unlikely that the machine can break loose with its own power, and the mud must be chipped or melted away. Chipping is very tedious and often impossible because of lack of space to work. Heat is usually more practical, but if the weather is extremely cold, very large amounts are required.

Melting Out. A blowtorch, the larger the better, is the usual tool for this work. The flame is moved back and forth over the mud surface, and the thawed material scraped off. The wheels, tracks, and other metal parts will conduct heat to the mud effectively, so that chunks can be undermined and broken off; but care must be taken not to heat the metal enough to take out its temper. If the temperature is very low, a small section should be worked at a time; if it is just about freezing, the flame may be moved back and forth over the whole area.

Hot water is effective if available in large quantities, as it will wash off the mud particles as they are thawed, exposing new surfaces to the heat. However, it may freeze on other sections of the machine while draining off. A portable heater may be used to blow a current of warm air on it, preferably under a tarpaulin. A flexible tube may be used to conduct hot engine exhaust.

More drastic measures are to erect a tent, or tarpaulin shelter, over the machine and thaw it with a stove; or to drag and push it with locked tracks into a heated building. But often the most practical method is to leave it until a thaw occurs, clean it off, and make good resolutions.

Wheeled Equipment. Rubber tired vehicles are not as apt to freeze down or together, as the flexibility of the tires prevents the ice from holding them effectively, and the rotating parts are ordinarily not as close to the fixed parts. If such freezing does occur, the same means may be used to thaw it, except that the rubber must be protected from heat.

The parts most vulnerable to freezing are the brakes, and here water will do as badly as mud. If the vehicle is used in very wet or slushy conditions, then allowed to stand in freezing temperatures, a film of ice will bind the brake linings to the drums. Driving back and forth on a dry stretch of road, even if only a few yards long, with the brakes applied, for a few minutes before parking will usually dry them out again enough to prevent this trouble.

Frozen brakes may be loosened by rocking the car back and forth with its own power, or can be thawed with hot water or flame.

JUMPING THE TRACK

A weakness of tracked vehicles is the possibility of going off the track. When this happens, it may mean that the track is in a heap alongside the machine, the track wheels are resting on the ground; but more often it means that the track rails are not engaging the wheel flanges properly, being displaced to either side, and contacting the inner surface of the track shoe. Operation in this condition soon leads to the complete separation of machine and track.

Jumping or running off the track occurs most often during sharp turns on uneven ground, and is likely to indicate that tracks

are too loose or have a broken link, or track and wheel flanges are worn, or that wheels are out of line. It is usually accompanied by a snapping or grinding noise, and if suspected, the machine should be stopped immediately and inspected, as every inch of movement makes it harder to get back on the track.

If the track is off the truck rollers only, it will usually swing back into place if the track is raised off the ground, by running the bull wheel or idler onto a log or other lift, or by jacking. If the bull wheel is on hard ground, forcing down a hydraulic dozer blade will often raise the track sufficiently.

The principle involved in getting a track back on a bull wheel or idler is similar to that of installing a tight fan belt on a car. It cannot be pulled or pried enough to stretch it over the flange of the pulley, but if it is held in one end of its place in the pulley, and the pulley turned, the wedging action will stretch the belt over the flange, and the part of the belt already in the groove will draw the rest of it in.

Similarly, with the track it is a problem of getting part of the track in line with the flange, and turning the wheel to draw it on. If the track is partially on the wheel, simply turning it in the proper direction does the job. If it is off the flange completely, it may have to be pried into line with a crowbar, jack, or chain, and the track adjustment will usually have to be loosened as well.

If the track is off the upper part of the bull wheel, but still engaged with even one tooth at the bottom, and with the truck rollers, the machine should be moved forward slowly. The sprocket teeth will mesh properly with track appearing from beneath the rear truck roller, and will carry the wrongly meshed section overhead into the slack upper section, where it will be straightened out by the support roller. If the upper part of the bull wheel is correctly engaged, and the lower section off, the track will work into place if the machine is reversed. However, it might be necessary to pry with a crowbar to prevent the track from jumping off the rear roller.

If the track is entirely off the bull wheel flange, but still meshed with the truck rollers, the machine should be moved forward. The bull wheel will roll onto track held correctly by the truck rollers, and, perhaps with the aid of vigorous prying, should mesh with it and pass this correct meshing up around itself. If the track is also off one or more truck rollers, the tractor should be backed so that the bull teeth can mesh with track held correctly by the support rollers. This may require more prying, or a pull in the correct side direction from another power source, or if the disabled machine is a shovel, from a line to its boom.

Should the track be off at the idler, the above methods are still good, with directions of travel reversed. If the track is tight, it might be loosened to facilitate crossing the wheel flanges. If the track is off the support roller, it usually can be replaced by lifting with a crowbar.

If the track is off the bull wheel, truck rollers, and idler but is still on the support rollers, the whole track and wheel assembly should be raised off the ground, and the bull wheel rotated backward. The track can be engaged with this at the top by use of a crowbar, and will be pulled into engagement with the rest of the bull wheel, then the truck rollers and finally the idler. Caution should be used to prevent the track from coming off completely in one place while being meshed in another.

If none of these stratagems work, or if the track is entirely off the wheels, the track adjustment should be loosened and the track "broken" by removing a lock and driving out one of the hinge pins, using the bull wheel as a brace. On some makes, there is only one master pin which can be

used. The side of the machine should be raised off the ground, the track placed correctly under the wheels, the machine lowered, and the track wrapped around the bull wheel and idler. The ends should be pulled or forced together at the bull wheel or between it and the top of the idler, by chain tighteners, block and fall, winch, jacks, elbow grease, or any other means available, and the pin inserted and locked. This is a difficult and laborious job, even on a small machine, except for experienced personnel, and on a large one may require the use of other machinery to handle the track.

It is sometimes easier to replace a track, after opening it, by walking the machine off it onto a plank or beam, aligning the track behind it, and walking it back, than to shift the track around under the machine.

This type of work has been rendered much more difficult by changes in track design and fabrication. A single master pin may be difficult to identify and to get at. When found, it may be so tight that it cannot be driven out until the links are heated with a torch, and the links may be bent by the heavy hammering, during either removal or replacement.

It is common practice among service men to cut a pair of links with a torch; then take the whole track to a press to be reassembled. A minor incident may be turned into an expensive and time consuming project in this way.

If the master pin is buffed down before inserting, it can be driven and removed with less trouble, and will usually still be tight enough to stay in until it becomes necessary to open the track again.

CHAPTER FOUR

CELLARS

Cellar excavations may be roughly classified as the dig-and-pile and the dig-and-haul-away types, which will be referred to in this discussion as residential and commercial, respectively, as the larger part of them fall into these categories.

Backfilling around the foundation is discussed in Chapter 7. It must be emphasized here that a wet fill can crumple in a foundation and even move footings, and that this danger is especially severe if the masonry has not had time to cure.

PRELIMINARY WORK

Tree Protection. In residential excavation, any clearing that may be required is likely to be of the selective type. Large trees, or trees of desirable species, may determine the location of the house, and they must be guarded against damage and burial. It may be advisable to wrap the trunks of such trees in cloth, and protect them by a collar of vertical boards, as in Figure 4-1. If their bases may be temporarily buried, the original ground line should be marked on the bark with paint, so that the fill may be removed accurately, and burial or overcutting avoided.

Topsoil. Topsoil is usually present and if it will be needed for landscaping it should be saved. This involves taking it off the area to be excavated, and preferably from the areas where spoil is to be piled. This stripping may be a substantial part of the cost of the excavation but is required in most localities.

In places where there is no well defined topsoil, or the topsoil makes up a third or more of the spoil and the subsoil will mix well with it, stripping may not be needed.

A method of stripping topsoil which is often most economical in the long run is to remove it completely from all areas to be involved in the digging. Figure 4-2 (A) shows one method of doing this by placing it in compact piles well away from two corners of the proposed house. This will usually keep it out of the way of digging, piling, and ditching, and leaves it in a position for straight line spreading. But it should not be put in corners where a dozer will be unable to get behind it.

(B) shows a more usual method. The digging and piling area is stripped, the topsoil being pushed into two piles, so placed as to be just beyond the spaces for the piles of spoil. If too small allowance is made for the spoil, the topsoil may have to be moved back further, or may get buried by the fill and partly lost. In any case it will probably interfere with backfilling.

In (C) the topsoil is pushed to the sides and fill piled to the front and rear.

Topsoil stripping is discussed in Chapter 10. It is customarily done by a dozer, which does the cleanest work. Hoe shovels, and to a less extent other shovel rigs, will remove topsoil rapidly, and if the soil is heavy and wet, may be preferred because they do not compact it and cause it to cake. If large areas are involved scrapers may be used.

If the topsoil is thin and will be required

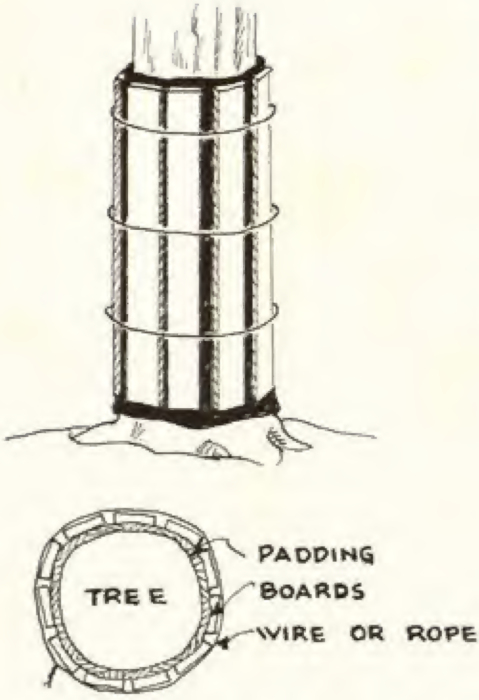


Fig. 4-1. Protection for tree trunk

for finishing off, it may be deliberately mixed with some fill while stripping to increase its bulk. If the subsoil has a loose texture, little or no harm will be done to fertility, and regrading will be simplified.

Artificial Obstacles. Serious digging difficulties may be caused by obstructions placed by the builder. Batter boards are used for reference in exact placement of foundation walls. They will increase excavation cost by restricting the movement of machinery, particularly if the house is to be irregular in shape. Piles of building material may also be much in the way.

Corner stakes, with back reference points such as are described in Chapter 2, are adequate location marks for the excavator, and other preparations for building should be postponed until digging is complete.

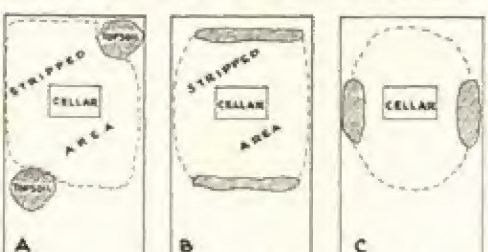


Fig. 4-2. Topsoil piling

Depth. The depth of the excavation depends on the first floor height relative to original grade, and the depth of substructure below it. Substructure might include floor thickness, rafters, sills, cellar headroom, and thickness of the cellar floor and gravel or crushed rock under it. If the full area is to be dug to the bottom of the footings their depth must be considered also.

On sloping ground, excavation depth will vary at different points.

Factors in determining first floor level, including a way to probe for rock, are discussed in Chapter 7.

Rock. Digging in ledge rock or large boulders may increase excavation cost three to five times, or more. Its presence may result in raising the house, or substituting a slab or crawlway for a cellar.

If it is to be removed, dirt removal should be completed and the rock surface cleaned before drilling.

Most cellar jobs are so located that mats must be used to cover blasts, and particular care taken to safeguard passersby and traffic, and to avoid damage to property.

DIGGING

Bulldozer. The three standard machines for digging small cellars are the bulldozer, the shovel dozer, and the hoe shovel.

A dozer can dig a cellar of any depth desired, provided heavy rock or mud are not encountered, but it is at its best in shallow work. This is because it must dig away a considerable amount of the bank to ramp itself in and out, and the whole weight of the machine must come up out of the hole with every pass. It can push much larger loads on a level or a moderate upgrade than on the steep rises from a deep cellar.

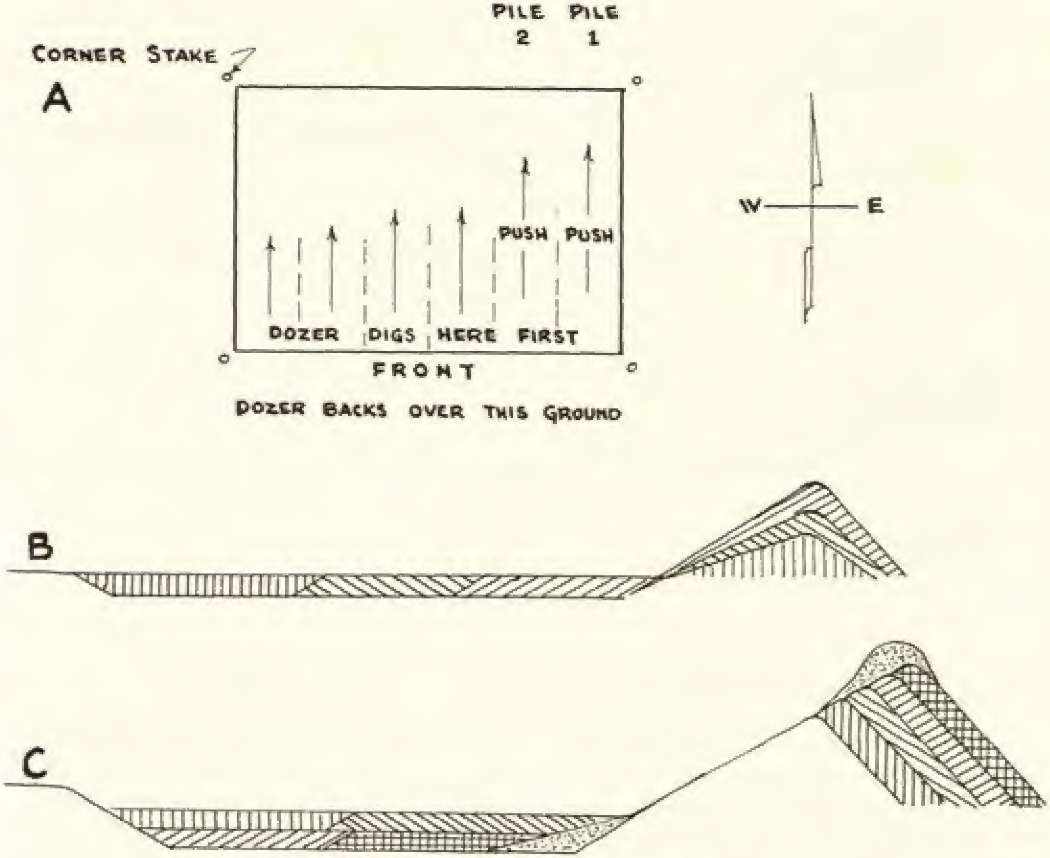


Fig. 4-3. Cellar digging sequence

Digging techniques vary with the operator and the locality. Several methods will be described, but they are presented only as samples and should be followed only where they give satisfactory results.

It is good practice to leave a ramp that will allow trucks to back into the floor of the excavation, for convenience in delivering foundation materials to the point of use.

Example. The first case to be considered is that of a cellar, 20x30 feet, four feet deep, dug in a large, level, treeless lot, from which topsoil has been stripped. The dimensions given are those of the outside of the foundation walls, and an additional eighteen inches on each side should be allowed for wide footings and working space for the masons, so that the dimensions of the hole should be 23x33 feet. Stakes are set six inches outside the digging line, as in Figure 4-3 (A) to avoid accidents to them. Any temporary guide pegs the operator needs are set along the edge, or just outside it.

OPEN FRONT METHOD

Top Layers. The bulldozer is first worked along the short dimension, inside the stake lines. The blade may be dropped at the front or south line for a fairly deep bite, and when filled it is lifted to ride the load over the undug ground until the north line is crossed. The dirt may be dropped at the line or pushed a few feet back. The dozer then backs to the south line and takes another bite in a strip adjoining or overlapping the first. It may work the whole width of the front line, as in (A), or only a section of it, before digging the area over which the soil has been pushed. The back edge of the cut is worked north by successive bites until the rear line of the excavation is reached, approximately as shown in the cross section (B).

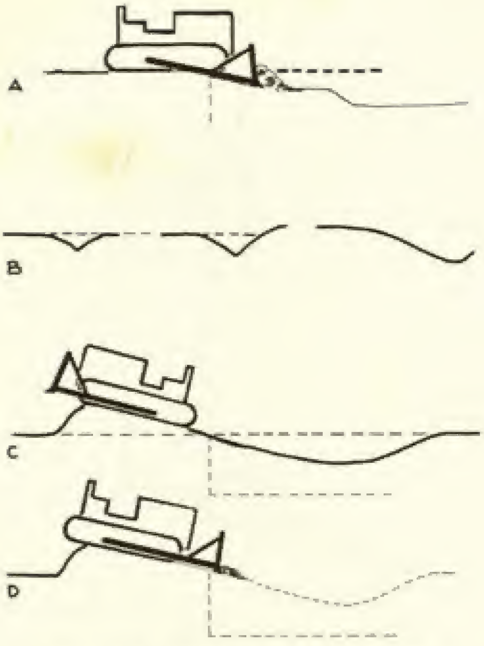


Fig. 4-4. Cutting down from edge

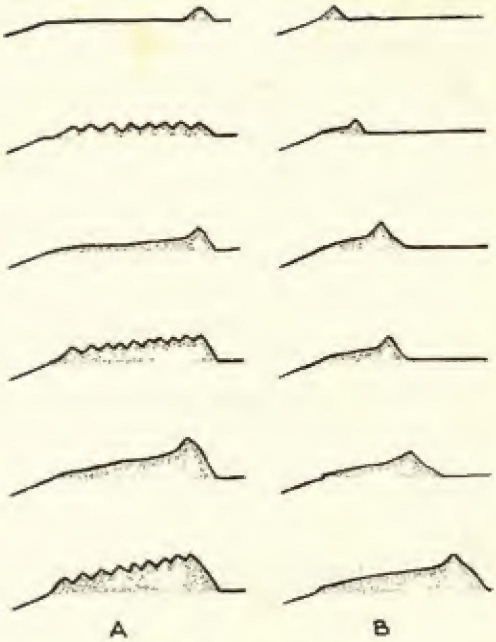


Fig. 4-5. Piling soil

After completing the removal of the top layer, the dozer may cut out and pile a second layer in the same manner, as in (C). This deeper cut will not extend to either digging line, as the slope down and the slope up are kept inside these lines. The east and west edges are also tapered in to provide slopes the dozer can climb.

This digging can be done about as well by making the first cuts against the north line and working successive cuts back toward the south line. However, the machine should not start a cut at the front line and make it shallow enough to continue to the back line, as the long move to the front is partly wasted unless a full blade is obtained there.

If the soil is so hard that the blade cannot be filled in a short distance, the dozer may be worked over a short digging area only, for several passes, after which the pile of loosened dirt may be pushed to the spoil pile. If a ripper or subsoil plow is available, it might be profitably used to break up layers of dirt in advance of digging.

Ramping Down. A hydraulic dozer, which is preferred for cellar work because of its ability to cut hard soils, will usually not cut a steep ramp down without special handling. Figure 4-4 (A) shows a dozer cutting down from a line in soft soil. If digging is good, the blade will penetrate rapidly until maximum depth is reached. It will make a level cut until the machine's center of gravity moves over the cut. It will then fall forward, and the blade will resume cutting until full penetration is reached, when it will level off again. Such a series of steps makes an unsatisfactory ramp.

One way to make a smooth ramp, shown in (B), is to start it well back from the edge with a gradual curve that is made steeper at the digging line. Cutting is then regulated so that the full depth of penetration will be reached as the center of gravity crosses the steepened part of the curve. Several passes are made in digging this ramp as indicated. This curve may be made steadily steeper as depth increases because the tractor itself is at a downward slope.

If the cut cannot be made far enough back into the bank for ramping in, the procedure shown in (C) may be followed. Dirt is pushed out of the excavation into a steep pile, the dozer is backed up on this, and

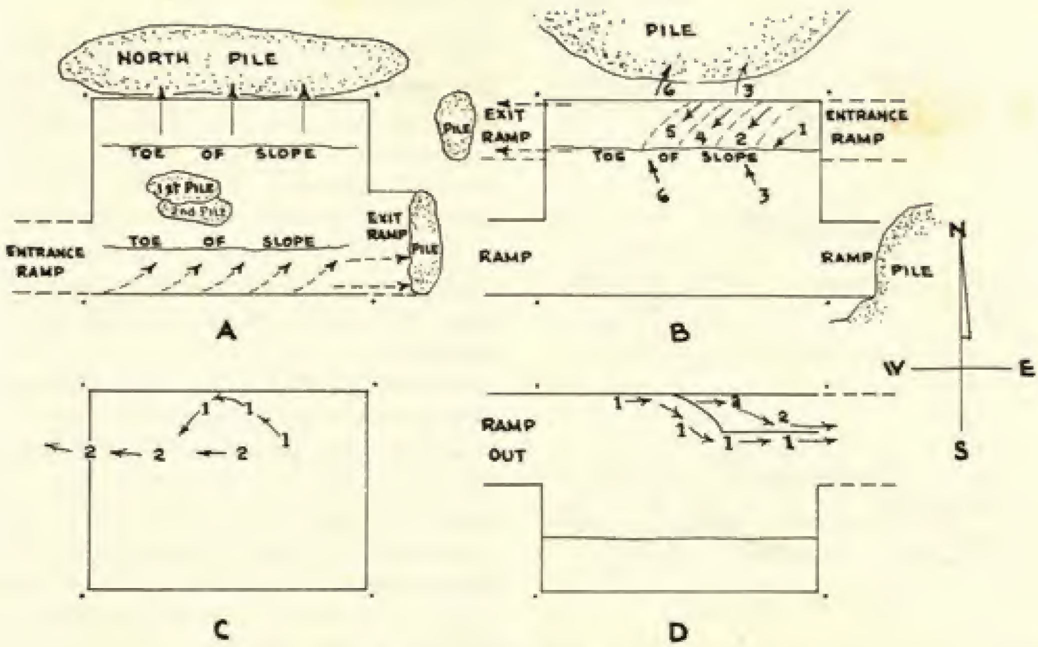


Fig. 4-6. Cutting lower layers

is thus pitched down a steep enough angle to cut down sharply.

Piling. The area to be occupied by the pile should be calculated or guessed at, and the first piles placed at its far side. Successive loads may be dropped toward the excavation, then a load carried over these, pushing the tops off some of the heaps, and dropped at the back. The pile is thus built up in a series of wedges, with their thin ends towards the excavation, as in Figure 4-5 (A).

Or the first load may be dropped at the near side of the intended pile, and the next pushed through it with a raised blade so that the approximate up slope is established from the beginning, and successive loads dumped off the back as in the (B) series. In either case, the pile may show a tendency to build toward the hole, and may have to be dug into severely to cut it back to proper distance.

The up slope of the pile should be made according to the power and traction of the dozer, the judgment of the operator, and may be between 1 on 5 and 1 on 2½. The easier gradients make it possible to push larger loads, but they must be moved farther and require more ground space.

Lower Layers. After the digging has reached the half depth, the dozer should be moved out onto the west bank and headed east along the south line of the excavation. An entrance ramp should be started several feet back of the west line, as in Figure 4-6 (A), and a steep ramp cut down toward the two foot level. As the blade fills, the machine is swung toward the center of the hole and the dirt left on its floor. The dozer returns to the south line, makes another cut, again swinging the spoil out into the center, pushing it somewhat farther. It thus cuts out the full width ramp by which the dozer entered the pit from the south, and occasionally shifts to pushing the dirt obtained from the ramp up on the north pile. As the east edge is approached, dirt may be pushed up on its bank, cutting a ramp, instead of to the north.

The north slope may then be cut away in the same manner, the spoil first being pushed up the undestroyed section of the ramp, as in (B), and finally onto the west

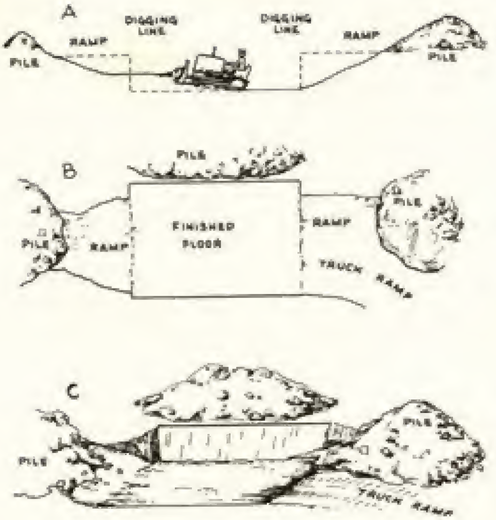


Fig. 4-7. Finishing

bank. These cuts result in vertical walls along the two long sides of the hole.

The inside ramps may also be removed by oblique passes from near the center (C), steering the dozer so that the blade is parallel with the bank by the time it reaches it. The slope ahead of the dozer can be gouged away in this manner, with the spoil being edged out into the open and pushed up the west bank. With the west section of ramp removed, the dozer can be turned to cut away the east part as in (D).

Finishing. After removal of the north and south slopes, the floor of the cut may be deepened by pushing to east and west. These ramps up to original grade should have their lower ends at the excavation line, and will therefore be cut back deeply into the bank, as in Figure 4-7 (A). Since a steep ramp means less extra excavation, the slopes should be made as steep as practical. They may be cut all the way through to begin with, for an easy gradient, and steepened as the hole deepens. The amount of dirt removed for ramps can be slightly reduced by narrowing them as they go up, as in (B). The ramps can be partly filled by the last loads pushed, as in (C), except where space is left for supply trucks.

As the bottom of the hole approaches final grade, it should be checked. A four foot stick, or a rule, may be used to measure down from the edges, if they are well enough preserved, or from a string stretched diagonally between two corner stakes. The mason contractor generally expects to do some hand leveling and trimming, but will be pleased to find it unnecessary.

It is not practical to dig narrow footwall trenches below the pit level with a dozer.

Results. The procedure outlined above should produce an excavation such as shown in Figure 4-7 (C) with two straight walls correctly spaced. Ramping out of the short sides reduces the amount of extra digging that is one of the drawbacks of dozer work. The whole front is left free for access and for piling building material.

However, the spoil may not be properly placed for backfill and grading. In such a location, a house would usually have the fill spread all around it, with particular attention to building up the front. Here, fill for the front yard would have to be obtained from the sides, which, in turn, might need to be partly replenished from the back. This involves extra pushing, and the presence of a few trees might make distributing it a major problem.

Time and Cost. This cellar involves about 120 yards of excavation. It might take a 40 horsepower bulldozer (a good size for the job) from one to three hours to strip the topsoil, and two to six hours to do the digging.

The machine might rate between \$6 and \$10 per hour, plus \$10 to \$30 for transportation to the job. Because of lost time between jobs, additional time or a full day might be charged.

Big savings can be effected if two or more jobs can be done in the area at the same time. It is often possible to dig one cellar, and backfill and grade for another, on the same trip.

Rock (even if not removed), water, irregularities, or obstacles will increase the cost of the work.

OTHER DOZER WORK

Four Pile Method. Another pattern for digging this same cellar is shown in Figure 4-8. The soil is pushed in four directions. The east and west ends, for a distance of perhaps eight feet from the line, are pushed up on the east and west piles, respectively, with ramps cut out of the bank and partly refilled as in the previous example. The section between these two cuts is pushed onto piles to the north and south, with ramps cut out of the bank beyond the digging line, each pile being supplied mainly from soil on its side of the center.

By this plan, the whole surface of the excavation can be worked down as a unit, the dozer always pushing dirt to the nearest pile. The four directions of push may be taken in rotation, or varied according to the operator's inclination.

Advantages of this method are efficiency in that pushing distance is kept to a minimum, and adaptability to grading plans. The four spoil piles are shown to be about equal, but their relative size may be changed without varying the method. Access and space for material is not as good as with the open front method. A larger amount of dirt is dug out for ramps and must be pushed back later.

Grading. If the topsoil has been pushed well back, it is possible to rough grade the fill at the same time that it is pushed out of the cellar, or immediately afterward. This has the advantage of making all four sides accessible to the builders.

Ordinarily, it is easier to spread several small piles than one big one. For this reason, it is wise to stop excavating occasionally and to spread the piles which have been built up.

The grade should be kept at least a foot above its final level, to provide excess soil for backfilling around the foundation.

If the digging is wet, the spoil may be too sloppy to spread immediately.

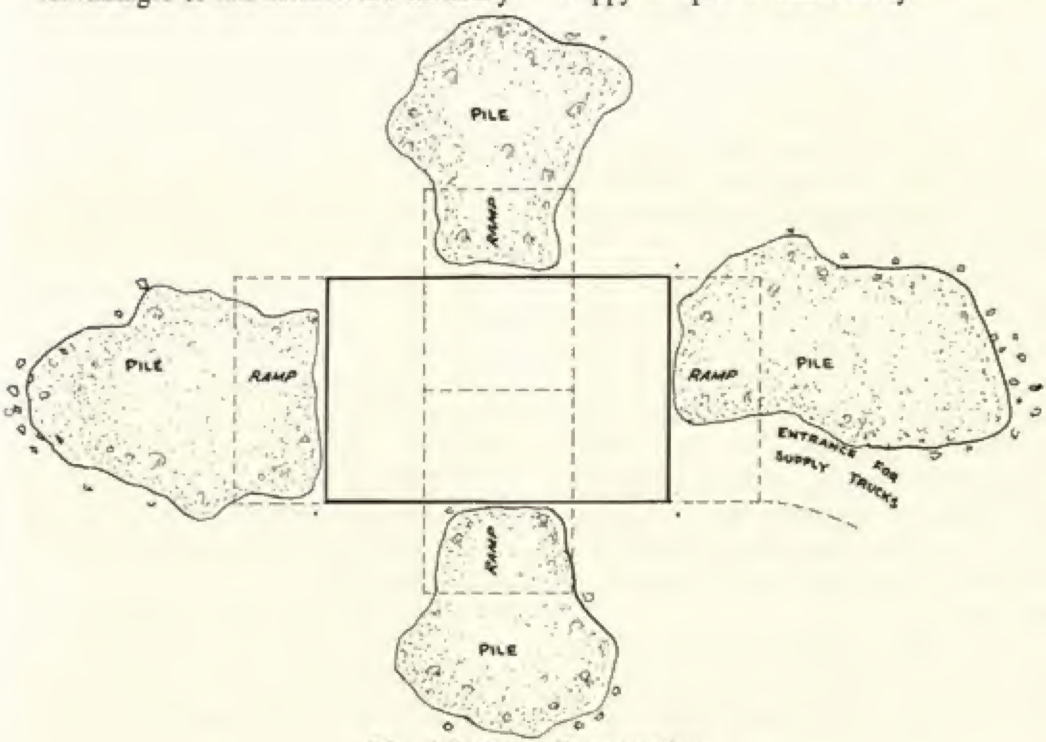


Fig. 4-8. Four-pile excavation

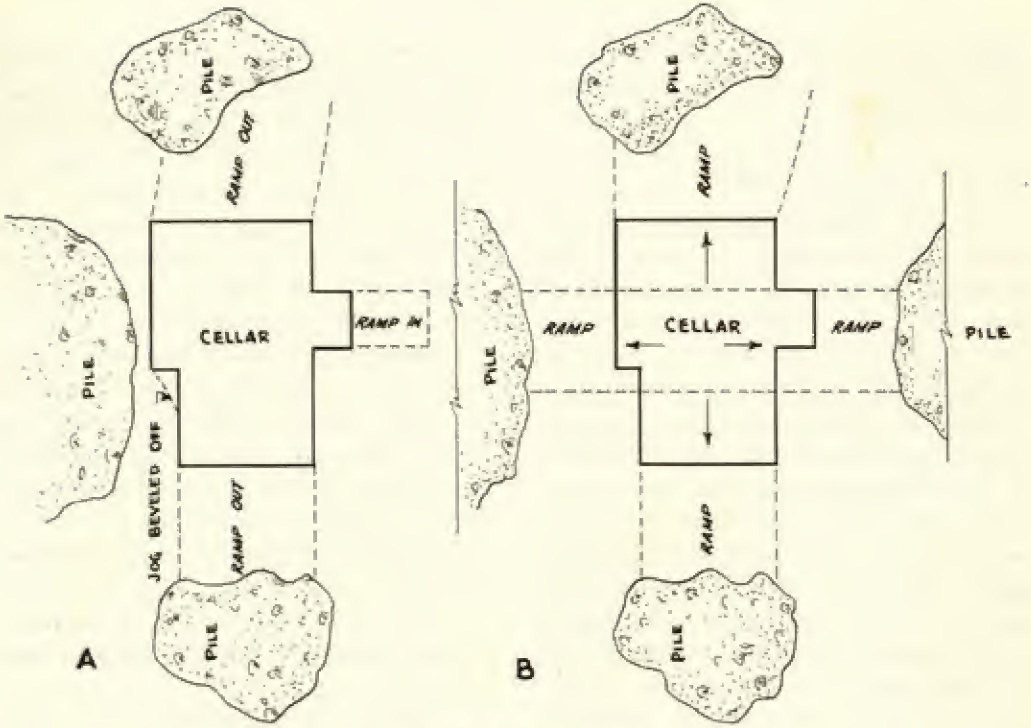


Fig. 4-9. Irregular cellar

Irregular Cellar. Figure 4-9 shows a cellar of irregular shape. This may be dug by the open front method by cutting back the jog as indicated in (A), and by pushing dirt for the small south room into the main cellar to be piled on the east side.

(B) shows the same cellar pushed up into four piles. The jogs are handled by simply moving the ramps and piles outward the extra distance.

Limited Access. Figure 4-10 shows a difficult situation where trees or other buildings permit entrance by the dozer at only three points, and where all the spoil must be pushed out at one of these spots. A detailed description of the work would be lengthy and tedious, and it is hoped that the successive diagrams are sufficiently clear. The dozer movements indicated by the arrows would have to be repeated on each cutting level.

In soft soils it might be possible to cut the corners with the dozer by pushing the dirt to loosen it, then backdragging. However, it is usually cheaper to dig them by hand and to throw the dirt out into the dozer path.

This type of excavation takes several times as long as open digging.

Figure 4-11 shows a succession of steps in excavation of a cellar in a hillside. This floor base is at grade on the east (right) and requires a cut of eight feet along the west line. The slope of this hill is about one on three, which a dozer can negotiate going up or down, but cannot safely work sideward, unless it is a wide model.

The easiest way to dig would be to push straight down the hill, but the yardage removed to ramp down would be about two thirds as much as for the cellar itself; and the spoil would be left in such a position that it could not be conveniently used to backfill the ramp.

Dirt may be pushed to the side as well as the bottom by pushing down from the center of the upper line of the excavation to build a step which would be level or

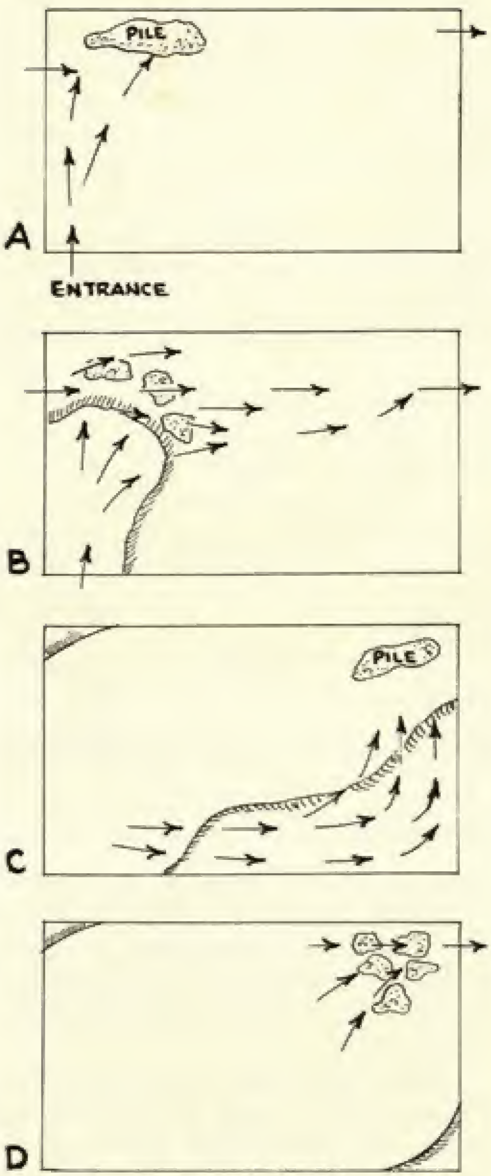


Fig. 4-10. One-exit digging

tipped oppositely to the hill slope. The dozer may then be operated on this step, pushing to the north and south, along the west line. The step will broaden as it is deepened, and will allow the dozer space to push downhill, first diagonally and then directly, in addition to the back cut parallel to the rear wall. By leaving the two rear corners for hand cutting, the excavation can be completed with small ramp cuts. If the dozer must do the whole job, the back wall cuts can be continued into slot ramps, which should be at least a foot or two wider than the blade to avoid getting the machine jammed against boulders or in slides.

SHOVEL DOZER

Digging. A dozer shovel or loader, if equipped with a full width hydraulic dump bucket, may dig an open type of cellar in the same manner as a bulldozer. It should be expected to do a quicker job than a dozer of the same power, because of better penetration in hard soil and ability to push larger loads. An exception would be wet slippery soils where the smooth tracks of the shovel would not grip.

The ability of the dozer shovel to cut straight ahead, then back and turn with the load, makes it possible to reduce the amount of excavation outside the digging lines for ramps. If the cellar is dug by the three pile or open front method, the procedure shown in Figure 4-12 may be fol-

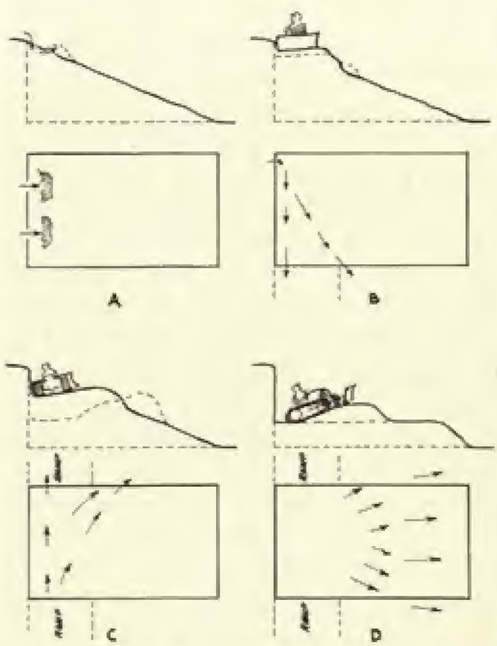


Fig. 4-11. Side hill cellar

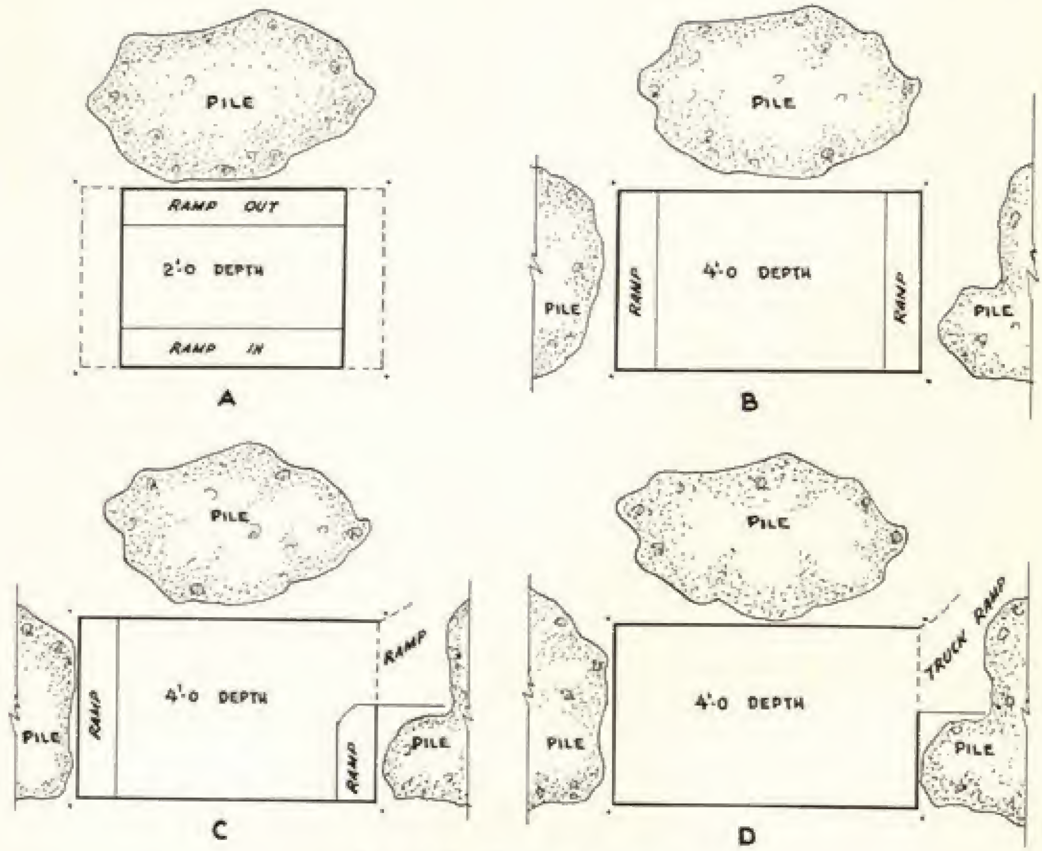


Fig. 4-12. Three-pile system

lowed. The first layer is not cut quite to the ends of the excavation, (A), and the ramps built in reaching the bottom are inside the digging lines, (B). They are cut back to the steepest practicable grades on the last pushes, and then one ramp, a foot or so wider than the machine, is cut into the bank. All soil left inside the digging line is then removed by being picked up and carried or pushed out the slot ramp.

The machine can carry a larger load up the ramp when moving forward than when reversing. This is because it is nose heavy when loaded, a condition which is made worse in backing up an incline, both by the shift of the center of gravity toward the front, and by the reaction from the driving torque which pushes the front down. In ascending a grade forward, both of these forces tend to raise the front and improve stability. These effects become more pronounced as the incline becomes steeper.

Turning around in a small excavation may be difficult, or impossible, so that it is often better to back out with a small load than to take the time to turn in order to carry a larger one.

Cutting Walls. When cutting back a wall, the bucket lip is driven into the base and raised. Low gear is used, and it may be necessary to slip the clutch, or alternately engage and disengage it, in order not to crowd the bucket under more dirt than it can lift or cut. When the back line of digging is reached, the bucket is driven into the bottom, the tractor held with partial application of the brake, and the bucket raised. As it rises, it crowds somewhat forward and the tractor should be allowed to roll back enough to compensate. If it rolls back too far, the clutch can be partially engaged to move into the wall again.

A cleaner bank can be cut by moving parallel to it and cutting with the side of the bucket, but there are usually some walls which are too short to be handled in this manner.

Any jogs or irregularities can be cut by digging into the wall from the excavation without making additional ramps. It is easiest to take these out in layers as the floor of the hole is worked down, but they can also be dug after completion of the main work.

Soil carried out of the hole may be spread or distributed to nearby low spots much more easily than by a dozer, and can also be readily loaded into trucks.

When the digging is done with a bucket narrower than the tracks, side walls must be cut head on, or in a series of curving gouges. Corners must be cut a little wide to make a clear right angle.

If a gravity dump bucket is used, it is difficult to cut a good ramp downward without placing a pile of fill and backing on it. Often, however, this type of bucket rises vertically and will cut a straight back wall without maneuvering the tractor.

Digging Under Buildings. A special feature of most dozer shovels is their ability to dig cellars under existing buildings. Particular attention must be paid to bracing the structure over the hole through which entrance is effected, and across any interior pillars which are to be moved. Digging should be done cautiously to avoid damaging the building through collision with rocks, beams, or soil pipes in direct contact with it.

If the building is not large enough so that the machine can dig a turning place inside it, it will be necessary to use hand labor to cut back to some of the walls.

Ventilation is very important, and usually requires at least the use of a powerful electric fan to keep the air reasonably free of exhaust fumes.

A machine that is to do much work indoors should have a scrubber (fume destroyer) on the exhaust.

Hydraulic shovels equipped with telescopic booms can dig under a building from outside, either directly or by removing hand-dug dirt.

BACK HOE SHOVEL

The hoe (backhoe or dragshovel) is the dozer's principal competitor for small cellar work. It can do a very neat job with little or no cutting outside of the excavation lines. It is capable of shallow digging, but compares most favorably with the dozers when the hole is to be over six feet deep, or when unfavorable bottom conditions, such as water, mud, boulders, or ledge are encountered. It is able to take care of any necessary ditching without change of attachments.

It is recommended that the digging lines be set a few inches outside of the required excavation, although in even textured soil the back hoe can do a very exact job. In addition to the corner stakes, intermediate guide pegs should be set at short intervals along the digging lines, as the operator cannot sight along these lines without getting down from the shovel, and the finished wall is established with the first cut.

Figure 4-13 shows the twenty by thirty cellar with the depth increased to eight feet.

Lining Up. Accurate lining up of the machine is essential for a clean job. If the cut is to begin along the south line, the shovel is placed as in (A) with the bucket about three quarters extended and resting a few inches beyond the southwest corner. The boom and the tracks are parallel with the south digging line. Lining it up in this manner is greatly simplified by marking the width of the bucket (including side cutters, if used), centered, on the bottom of both dead axles, with paint, or better, stubs of welding rod. Sighting across the outside pair of these marks from the rear, the outer edge of the bucket should be exactly in line

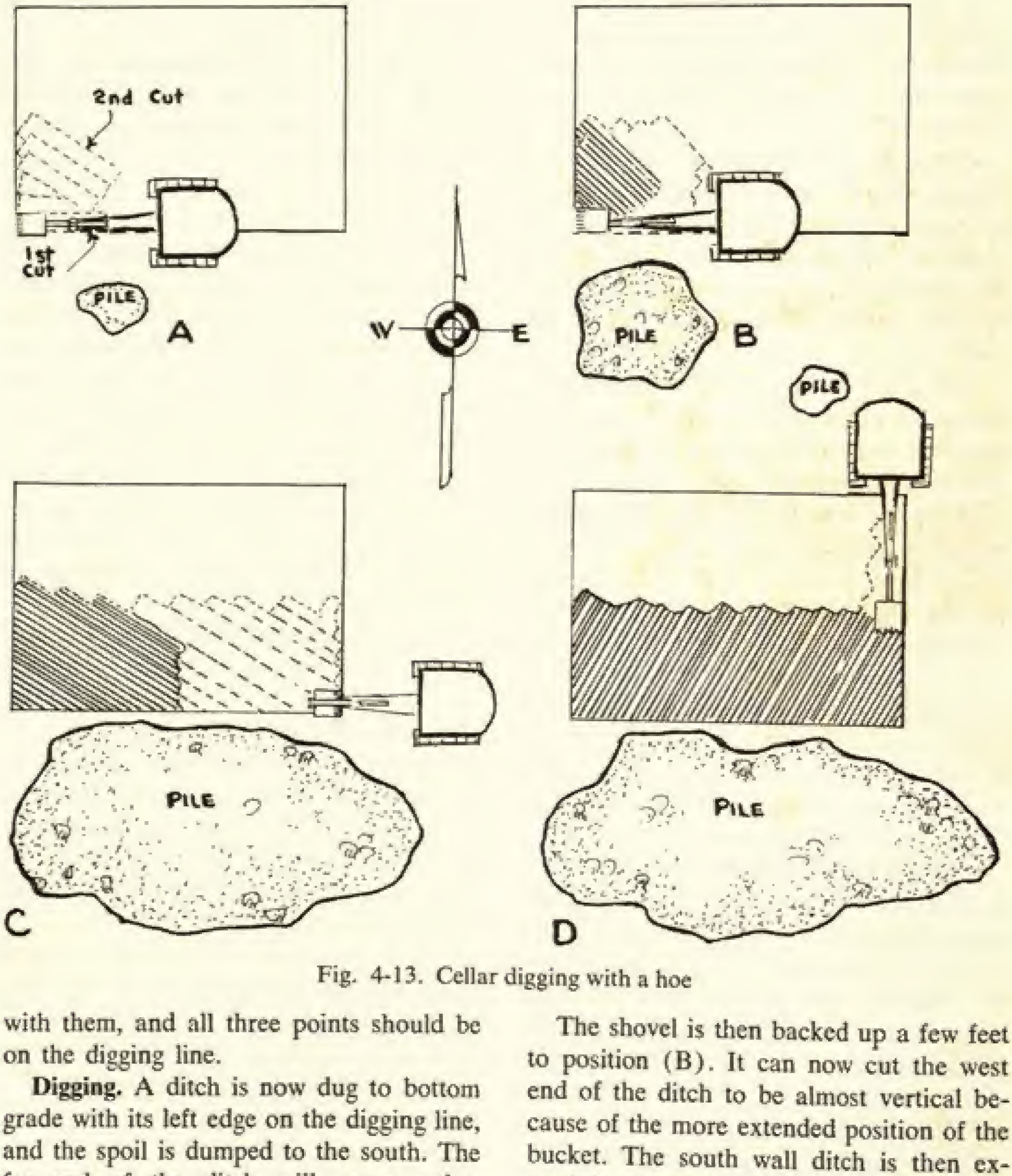


Fig. 4-13. Cellar digging with a hoe

with them, and all three points should be on the digging line.

Digging. A ditch is now dug to bottom grade with its left edge on the digging line, and the spoil is dumped to the south. The far end of the ditch will curve rather sharply inward. When the shovel has dug as much of the south wall as it can from its position, it reaches to the center of the west line and digs a trench back from there. The triangle included in these ditches is dug in layers to bottom grade, which may be found by a measuring stick, and as near to straight down from the west line as possible.

The shovel is then backed up a few feet to position (B). It can now cut the west end of the ditch to be almost vertical because of the more extended position of the bucket. The south wall ditch is then extended as near the shovel as possible, and material between it and the center cut down in layers to the bottom. The center line will be irregular.

The spoil pile will tend to build up too sharply at the edge of the hole unless pushed back. This pushing may be done by regulating the outward swing of the bucket during the dump so that it strikes the pile at a spot where its momentum will push

a considerable quantity of dirt outward, without stopping its own motion. Knocking dirt back should be started early, before the pile gets high. The hoist clutch must be engaged during this operation. The quantity of dirt that can be put in a pile is greatly increased this way.

Digging is continued in the same manner with careful attention to a clean, level bottom until the east end is reached. The shovel can probably cut this to a nearly vertical wall immediately in front of it, but will leave a ragged edge, as (C) further north. The shovel is then turned and walked into the unexcavated north section. When its center is a half bucket width inside the east line, as in (D), it stops and shaves the end of the excavation, then trenches to the north edge. It next straddles the north line, and is lined up in the same manner as before, with the bucket resting in the hole in the northeast corner.

The north section is excavated in the same manner as described for the south, and completes the excavation. The west edge may be cleaned up, if necessary, by turning the shovel to walk parallel to the edge, so that the bucket can dig straight up. The shovel should not be put in this position, however, unless the soil is firm and is known to have good load bearing qualities, as a crawler machine is vulnerable to cave-ins or slumping under one track.

This edge may also be trimmed from the north and south banks.

The completed excavation and spoil piles are shown in Figure 4-14. It will be noticed that the piles are somewhat offset from the hole, so that the south pile can easily be used for fill on the east end, and the north pile on the west end. Both ends are left open for access and storage.

The north cut could have been made in the same direction as the south cut, if the east ditch were shorter, but the fill would then have been concentrated toward the east end.

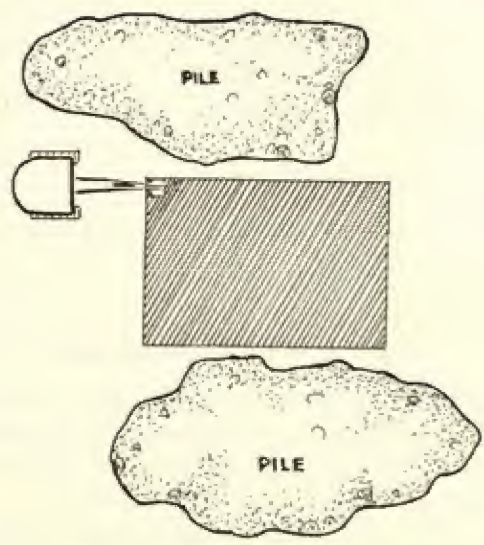


Fig. 4-14. Finished excavation

If the spoil showed a tendency to slump into flat piles, or the cellar were deeper, the shovel might not be able to stack the spoil in these two piles, unless it occasionally left the digging and walked behind them and dragged them back, thus making room for more.

A more finished hole could be made by starting the digging with a ditch along the west edge, dug from the south. The spoil pile would largely block the access to that side, unless the soil were piled in the cellar area for rehandling. If access were not important, this ditch could be widened toward the center, reducing the amount to be piled to south and north. Existence of such a ditch would make it necessary to work the north section toward the east.

Loading Trucks. A hoe can load the spoil in trucks instead of dumping it on the ground. Where the piles will be so large that they will have to be dragged back, a truck or trucks may be used to take part of it away, the shovel continuing to dump on the piles when no truck is in loading position. If grading plans have been prepared requiring use of the fill away from the foundation, it may be cheaper to truck

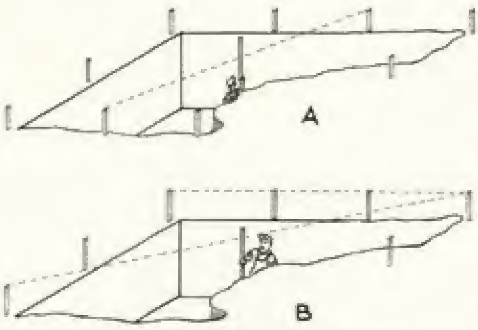


Fig. 4-15. Checking bottom grade

it than to push it later with a dozer. However, enough of a pile should be left by the hole for backfilling between the foundation and the edge of the excavation.

The pull shovel can dig footing trenches below the floor level where it is working parallel to the edge, as along the south, east, and north walls in the original procedure.

Checking Grade. Cutting the bottom to proper grade is more difficult with a shovel than with a dozer, as the shovel operator looks down at the grade rather than along it; has more difficulty climbing down to check it; and cannot move the machine back to grade over mistakes.

It is very helpful to the operator to have a man to check his work, although he can manage alone if necessary. The corner stakes, and preferably some other stakes, may be marked at a certain height, as nine feet above the bottom. In a level field the marks would all be a foot above the ground; in a sloping one the highest stake should be marked a little above the ground, and the others with the aid of an instrument or a string level. A stick should be cut nine feet long.

If the operator is checking the grades alone, he may fasten a taut string between two stakes so that it will go over the spot in question and measure the distance from the floor to the string with the stick. Spots which cannot be crossed by the string, or measured directly from the height of the wall, may be checked from a known spot by eye, or with a hand or carpenter's level. See Figure 4-15 (A).

If two men are doing the work, a string may be stretched between stakes on one side. Another string fastened to another stake across the excavation may be held in any desired position on the first string, as in (B), while the other man holds the stick.

Hand and transit levels may be used. A long rod is required if the instrument is set up outside the hole.

A shovel cannot cut a perfect floor to a pit because of the projection of the teeth and the tooth bases. The smoothest grade is obtained when the bottom of the bucket is used for finishing rather than the teeth.

Irregular Edge. Figure 4-16 shows a cellar of the same irregular shape as that in Figure 4-9. The principal considerations in doing complicated excavations with a hoe are to avoid digging it into a trap; to avoid surrounding it or blocking it from other work by piles of spoil; and to work either parallel or at right angles to outside edges.

There are several ways in which this cellar can be dug. The north side can be dug from the east end as in (A) and (B). When the jog is reached it is finished off with a vertical cut, the shovel backed away, and brought back in position to cut along the inner line. If the start is made at the west, the cut is brought a little beyond the jog, and position then shifted to dig along the outer line.

The machine may dig the south side by entering from the west and starting at the southeast corner. Excavation is carried back to the west line first ditching the edge then digging out the center. Care is taken to begin the spoil pile well west of the south room. The shovel is then moved off to the south and up to the room. It is first lined up to the west side of this room and makes a cut from the main excavation to the south line of the room. It is then moved

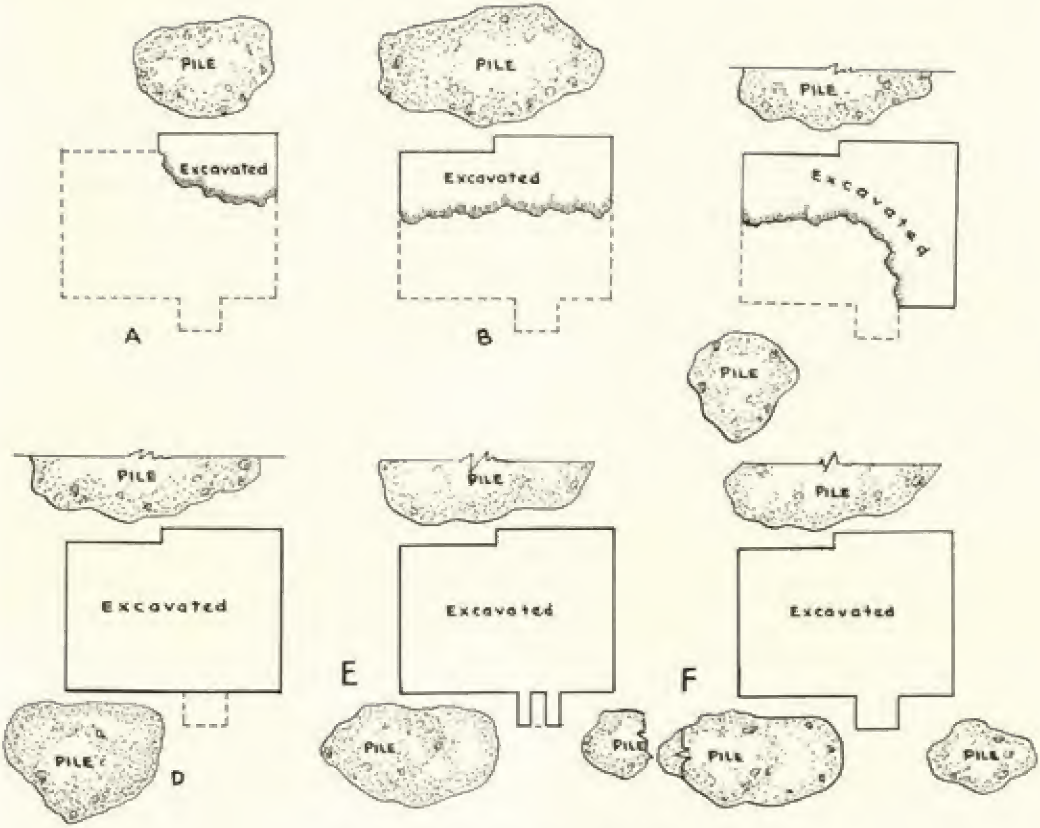


Fig. 4-16. Cutting jogs with a hoe

so as to cut the east wall of the room, then digs out the rest of the room.

Another way to do this would be in the same manner as the north wall, treating the room as a double jog. However, this would involve extra digging because the bucket needs considerable width in which to cut down.

If the excavation site is a hillside, the work should be managed so that shovel tracks will head up- or downhill, not across. If the grade is steep, the shovel should dig from downhill to avoid danger of being pulled into the hole if the bucket hooks into something solid.

If work must be done from the upper side the stability of the ground should be checked, and both tracks must be securely blocked against sliding.

OTHER SHOVEL RIGS

Dipper Stick. Dipper stick shovels are seldom used in residential cellar excavations, but they can do a good job. For satisfactory results, the ground should be firm at bottom grade, and the spoil should build into steep-sided piles.

A 20x30 cellar, six feet deep, can be dug as shown in Figure 4-17 (A). A somewhat larger excavation would be dug according to the diagrams, Figure 4-18. In each case, a ramp must be dug outside the excavation line with a slope, usually 3½ and 2½ on 1, which the shovel can climb when the job is finished.

The spoil piles can be pushed back from the edge of the hole to some extent by crowding against them with a closed bucket.

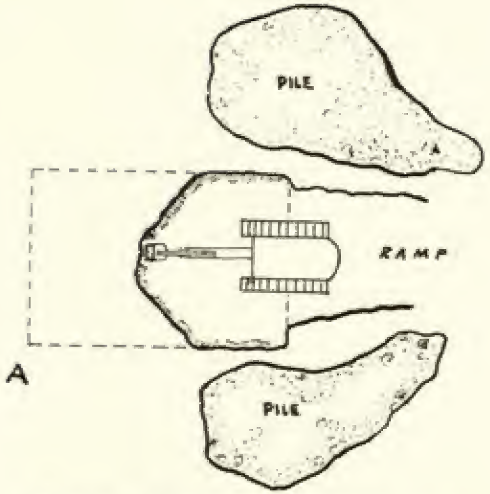


Fig. 4-17. Large dipper in small cellar

The walls of the hole tend to slope in at the bottom, and to be somewhat jagged because of the different angles at which the bucket cuts them. Both these features can be reduced or eliminated by careful digging, but extra time will be consumed.

Clamshell. Clamshells are not ordinarily used in this type of excavation because they do not move as many yards an hour as competitive types. However, they turn out as accurate a job as a hoe, and for small deep excavations, will do the work cheaper than a bulldozer. Digging is done from the top so that no ramps are required.

An edge may be cut with the tracks parallel with it, and the tagline chains attached to one jaw, or with the tracks at right angles to the digging line, and the tagline on both jaws. Either of these arrangements will permit cutting straight sided trenches along the outer lines. The center is best cut in layers, or in sections behind completed edges.

A medium or heavy duty bucket should be used. The spoil may be placed in isolated piles, in windrows, or in trucks as desired.

MULTIPLE CELLARS

In many residential developments, small

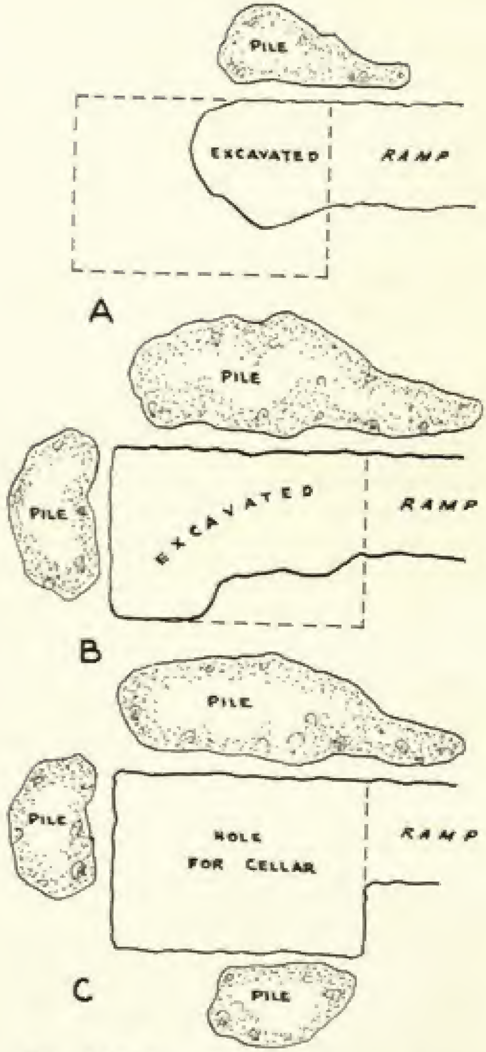


Fig. 4-18. Two-pass dipper excavation

houses are built close together in straight rows. Under such circumstances it may be economical to dig a wide trench straight through the block, and backfill between the houses after the foundations are built.

In Figure 4-19 the digging is done by a dragline or a large dipper shovel which piles the spoil on both sides. Materials for foundations are trucked and piled on the floor of the trench. After the foundations are up, the piles are bulldozed around and between them, and the surplus used to

build up the grade throughout the area.

Use of part of the spoil for raising the ground level decreases the depth of digging necessary.

Another method of line digging is to use a dipper or tractor shovel, load all spoil into trucks, sell or dispose of part of it, and use as much as is necessary for backfilling spaces between other houses in the same development.

A third method is to haul away all the spoil for use elsewhere, and obtain backfill by dozer cutting on the uphill side of the houses.

The first method requires at least partial backfilling as soon as the foundations are up, to provide access to building material. The weight of the fill and of the large dozers commonly used, are likely to break in uncured foundations, particularly if they are not braced by first floor beams.

Waiting for foundations to set will delay construction materially.

A large dragline might be able to pile all the spoil on one side to allow access to the other.

The other methods give immediate access to the front and back, and allow space for piling materials. Backfilling can be postponed until the building is completed. Deeper excavation is required as the general grade is not raised by the dug material.

Relative cost will depend partly on the value of the spoil removed.

HAUL-AWAY DIGGING

Trucking Spoil. In large commercial excavations of the haul-away type, one of the most important considerations is arranging for the disposal of the spoil, except when it is to be used as fill on the same project. It may be possible to sell it profitably, or it might be necessary to pay someone for the privilege of dumping it.

Disposal arrangements may not only determine the price to be charged for the digging, but also the time of starting the work,

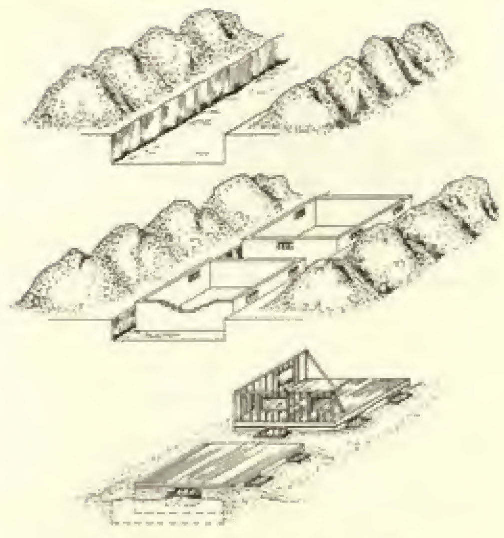


Fig. 4-19. Multiple cellar cut

and the number and type of excavating and hauling units to be used.

The distance to the dump may be much farther for the trucks than for a car because of restrictions on trucking on residential streets. An inspection should be made of the dumping site, and any price quoted for fill should contain provision for additional charges for dumping delays.

Permits. An excavation contract should specify that the owner, or general contractor, should be responsible for obtaining all permits necessary for the work. If the job is stopped because of failure to have such permits in order, the excavator should have the privilege of charging for the tied-up equipment on an hourly basis.

Machinery. If the excavation is large, the dipper stick is the preferred machine, unless the pit floor is too wet or sandy for trucks. The dipper is the fastest loading machine. It can cut walls and floors with reasonable accuracy, and it is not hampered by obstructions just outside the digging line, or by rough or steep ground surface.

When the cellar is small, wet, or sandy, a backhoe is better. Its smaller output is more than compensated by accurately cut edges, truck loading on top, and ability to

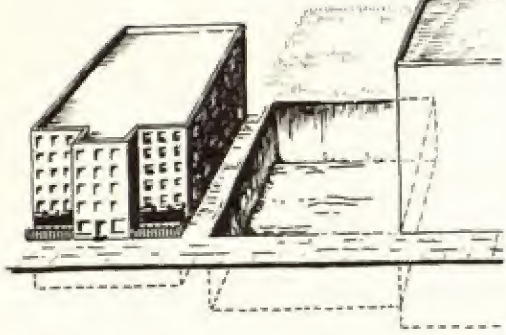


Fig. 4-20. Haulaway cellar job

work without a ramp. If the hole is to be very deep, a clamshell will be used.

Ramps. In most cases, the dipper shovel cuts a ramp down, inside the digging lines, which must be of such grade and material that loaded trucks can climb it. The grade may be between one on five and one on twelve, depending on the power of the trucks and the loads placed on them. The slope is made as gentle as the length and depth of the hole permit, so that larger loads may be carried and breakdowns reduced.

If the plot is sloped, the ramp should be cut in from the lowest point on the edge to which trucks have access.

Earth ramps are generally removed immediately upon completion of the excavation they serviced. It is usually necessary to bring in a backhoe or a clamshell for this job, unless the yardage involved is so small that it is cheaper to dig it by hand. Low ramps can be loosened and partly removed by the shovel digging behind it as it moves out.

Timber ramps afford less tractive resistance and better footing than earth, and so can be built with a steeper slope. They can be left in place during construction of the foundation for convenience in moving building material. However, timber work is so expensive that these ramps are largely limited to use in excavations that are very deep in proportion to their size.

If space allows, the ramp may be dug outside of the cellar area. This involves extra digging and backfill, but may be justified if a dipper is the only shovel available and spoil can be piled near by, or when other work on or near the premises will produce enough spoil for backfill. Refilling cannot be done until the foundation is built and first floor timbers placed, and it should be carefully compacted so that it cannot soak up enough water to become a liquid mud and exert hydraulic pressure against the wall.

Pit Floors. The shovel may dig the floor of the pit exactly to grade, or may dig portions of it below grade, to allow room for disposal of spoil from hand dug trenches or removal of the ramp.

Sometimes the whole cellar is dug to the bottom of the footings or piers, and sufficient spoil piled just outside the excavation to refill to cellar floor grade. A clamshell may be used to put the dirt back in the hole, and a bulldozer to spread it. A small bulldozer can be lifted in and out by the clamshell.

EXAMPLE

Figure 4-20 shows a basement layout for a business building. The excavation is to be 90′ by 120′ for an 88′ by 116′ building, eighteen feet deep, in a level plot measuring 100′ by 200′. The structure will be against the sidewalk line, seventeen feet back from the curb, will touch an existing store building on the east, a ten foot driveway backed by another building on the west, and a proposed parking lot. The footings of the east building are below the eighteen foot level, those on the west are twelve feet below the surface.

The site has been cleared, but two large stumps have been left. The topsoil is of such poor quality that it will not be separated. The contractor owns a three quarter yard shovel with dipper, pull shovel, and clamshell attachments. This machine is

somewhat undersize for the job but may be used unless a premium is placed on speed.

The dipper stick is used because of digging and loading efficiency. The ramp is located at the street as there is no access to the other sides except through the driveway, which is too narrow for heavy trucks and will be undermined by the digging. The ramp is next to the driveway, as if the other corner were used the store building might be damaged by collision or vibration.

Moving In. Arrangements are made to prohibit parking in front of the work area before machinery is brought in.

The shovel is unloaded from the trailer onto planks laid on the street to protect the pavement, or directly onto the sidewalk which is not protected because the trucking will destroy it anyhow. Digging is commenced in the sidewalk, or at its rear edge, and sloped down at about a one on five or 20 percent grade, in a cut thirty to forty feet wide. Trucks are first loaded when standing in the street, parallel to the curb. As the digging progresses, they are backed across the sidewalk and down the ramp, as in Figure 4-21.

It is necessary to have one man, preferably two, assigned to prevention of tangles between traffic and trucks. These should be policemen, or contractor's employees authorized by the police to do this work.

Trucks should be backed into both sides of the ramp, as in (B), and faced directly away from the shovel while being loaded. At least one truck should always be in loading position.

Trimming. As the cut progresses, the foreman checks the left edge for accuracy. Because of the angle at which the bucket works, it cannot make flat cuts on the wall, and one or more laborers should trim the face, either working from the top or from the ramp surface beside the boom. Checking may be done by stretching a string along the digging line at the top, and lowering another string to which a plumb bob is attached.

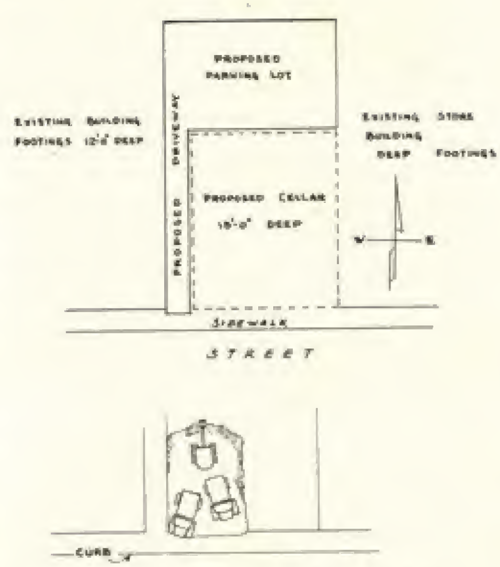


Fig. 4-21. Starting large cellar

Bank Height. The shovel would be able to take the full eighteen foot depth in one cut but this would not be good procedure. The shovel cannot cut a straight face higher than the level at which the bucket teeth start to turn away from the bank, and the face above might overhang or break back beyond the digging line. Hand trimming is more difficult on a high face, and caving is more likely and more serious than from a lower one.

The bottom is more likely to be muddy, or to contain rock outcrops than higher levels, and it is economical to remove as much soil as possible under good conditions, before tackling the difficulties. In addition, trucks hauling from an upper level have an easier climb to the street.

Under average conditions, this job would be dug in two layers or benches of about nine feet each.

Bulldozer. A bulldozer may be used to advantage to dress up the ramp and keep the pit floor smooth, and may be useful to push weak or overloaded trucks up the ramp. The smallest bulldozer can handle

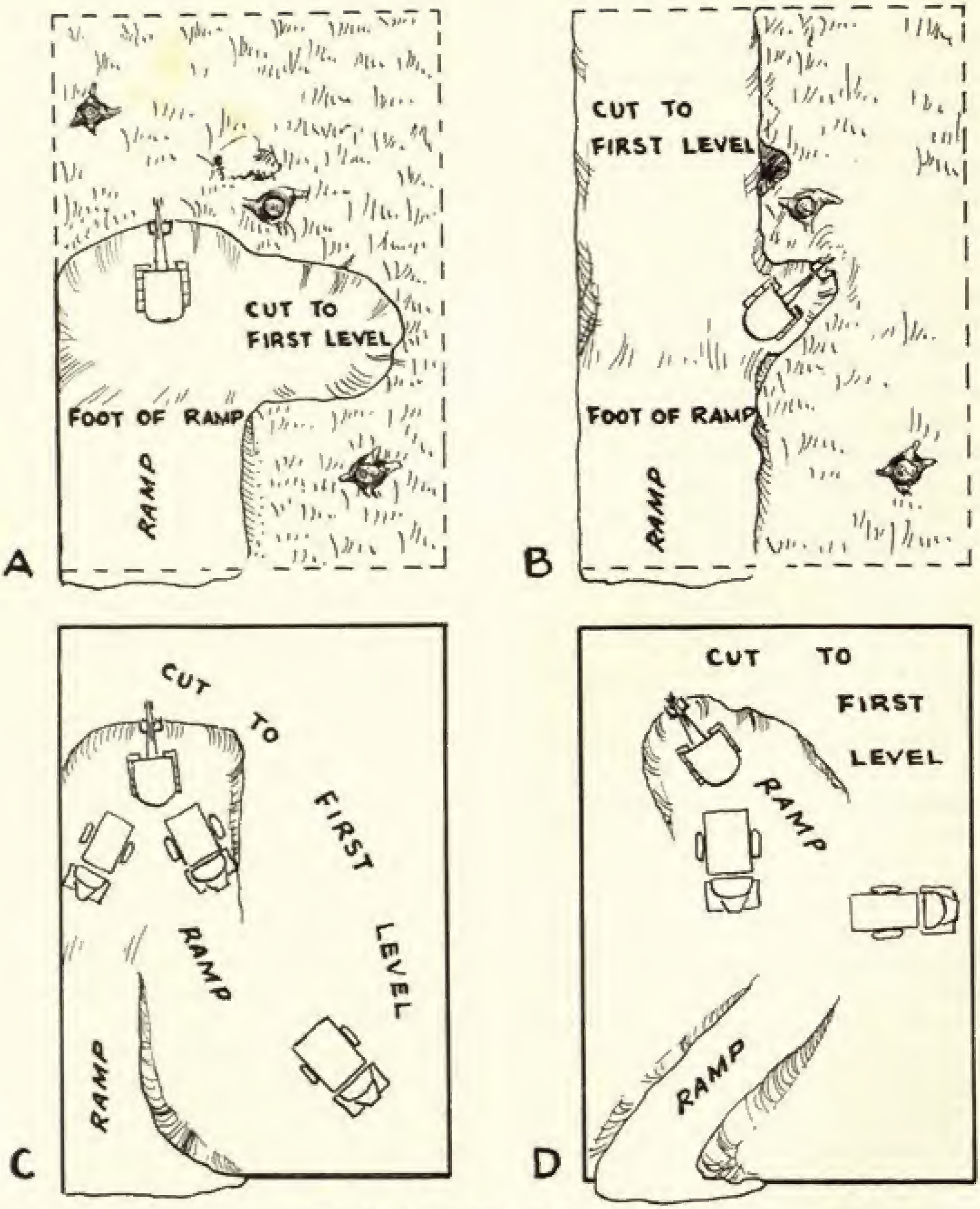


Fig. 4-22. Cutting first floor and ramp

the grading work, but a medium or large one would be needed for effective truck pushing.

Trucks. Trucks with four to eight yard capacity are well matched to this size shovel, but anything from three to twelve yards can be used. Small ones can maneuver more easily and work well on certain types of soft ground. Large ones cause less traffic congestion, and under favorable conditions will move soil at lower cost. If the pit is wet or sandy, all wheel drive machines are preferable. Trucks must be in good condition to carry capacity loads up the ramp.

First Cut. In making the ramp, the shovel has worked straight ahead. Upon

reaching the floor level of the first cut, it may continue to the back wall, or it may first make a side cut, as in Figure 4-22 (A), so that trucks can turn around in the pit. If it works straight through to the back wall, it is then walked to the foot of the ramp again to take another slice toward the back, as in (B), as double spotting of trucks is easier working away from the ramp than toward it.

Once the pit floor is widened enough to allow trucks to turn, the digging may be extended in any direction so long as the shovel may be easily reached by trucks. Sooner or later the bank to the east of the ramp is dug away, and usually part of the ramp itself, leaving it wide enough for one truck only. Since there will eventually be an 18 foot drop off its side, it is wise to leave a generous width, and, if the stability of the soil is doubtful, to shore it up as well.

Stumps. When stumps are encountered, the shovel should dig around them before tackling them directly. The depth of this cut is such that they can be undermined enough so that their own weight will help to break them out. Roots can be cut easily at a distance of a few feet from the trunk, and the stubs splintered back. Many operators will waste much time, strain their machines, and break cables by direct attacks on stumps which would shortly fall out in the ordinary course of digging.

When the stump is loose, it should be knocked around with the bucket to loosen the dirt, then placed in a truck. The tailboard should be folded down or removed unless the stump is to be lifted off. With skill and luck, the shovel operator may be able to balance the stump on the bucket, then tip it off onto the truck. It may be picked up also by a chain. If it is too heavy for the shovel to lift, the dirt should be dug out of it by hand, and all possible wood removed from it by sawing and chopping. It may be blasted apart if necessary.

Barricades. As digging approaches the sidewalk, barricades must be erected to keep spectators from climbing or falling into the pit, and from using any part of the sidewalk likely to cave in. These barricades may be solid wood fences, or may be perforated so that sidewalk engineers may watch the work. The contractor may be able to build up local goodwill by encouraging spectators.

Furnishing adequate windows or peep holes reduces the dangerous practice of spectators standing in the truck driveways to watch the work.

Finishing First Cut. The floor grade of this first drop is approximate, and a foot up or a foot down is not important as long as it is easily passable to trucks. However, the walls must be cut to whatever finish the job calls for. A good operator can cut a straight wall and an almost square corner with the bucket, but hand finishing is neater and saves machine time.

Bottom Cut. When the first level is complete, ramp cutting is resumed until the bottom is reached, as in 4-22 (C). Trucks will drive down the upper section, turn on the upper level, and back down to the shovel. It is not necessary that the ramp continue in the same direction, but this is the most economical method where the pit is long enough. Any turn must be made very wide for the convenience of the trucks.

Cutting of the lower level proceeds in much the same way as the upper, except that the strip alongside the ramp is left until the last for any bracing value that it may have; and the floor grade must be carefully watched. This is usually checked with a transit or a builder's level. If foot wall trenches below the floor level are required, they may be dug by hand immediately after trimming of the wall is complete, and the spoil moved to the shovel by bulldozer or wheelbarrow, or spread on the pit floor.

A somewhat gentler ramp gradient could

be obtained by using a diagonal or a zigzag ramp, as in (D).

SHOVEL TEAMS

Two Shovels. This job is big enough to justify the use of two shovels of the three quarter size or larger. The second shovel might ramp down from the sidewalk along the east side, and cut through to meet the first one at the center. After this, one ramp might be used as an entrance and the other as an exit; or one might be cut away. Or the second shovel might be brought after the first one reached the upper level, and using the same ramp assist it on that level or ramp down to the bottom.

Traffic. An external factor which may limit the number and size of shovels in such an excavation is traffic congestion on the street. This may create a bottleneck that would leave a line of empty trucks parked waiting in the street with the shovels half idle for lack of trucks to load. In congested areas, traffic may be one of the principal problems of the digging.

Ramp Removal. When the digging is complete except for removal of the ramp, a hoe or a clamshell must be employed. This ramp may contain three to five hundred yards, a sufficient amount to make the use of the faster digging pull shovel (hoe) better than the clam. If the hoe has an effective downward reach of sixteen feet, it will leave a bit of the foundation of the ramp for hand labor; but the clam, in taking the whole ramp out, is apt to require a larger amount of hand labor assistance while working. Another factor may be that the shovel at this job with a crane (clamshell) boom, might pick up extra work lowering materials into the excavation. The hoe rig is awkward to handle and to transport when detached, so that it might be more economical to move the shovel to the yard to change over and bring it back than to pick up the hoe equipment, bring it to the pit, and take away the shovel front. The clam rig could be loaded on a truck by a chain hoist or a tractor loader, and moved with little or no blocking.

It might also be good business for the contractor to hire a hoe or clam and move his dipper on to another job.

Whatever machine is used, it will probably stand on the ramp as it tears it up, as the driveway is too narrow for swing space, and for safety at such height.

Teaming Dipper and Hoe. If two shovels are to be used for the whole excavation, it may be that the larger one of them would be a dipper and the other a hoe, although under the ideal conditions considered so far, it is not likely. In such a case, the dipper stick ramps down on the building side, unless danger of vibration damage is unusually severe. The strength of the foundation wall might be checked, and permission obtained to brace it from inside if the weight of trucks on the ramp seem to threaten it.

The hoe shovel is assigned to cutting the north and west walls of the pit because of its ability to make a smooth straight cut without hand trimming. It would preferably start on the north side, cutting from east to west, keeping the line in the manner described earlier, and digging out as much of the center as could be conveniently reached, as in Figure 4-23 (A). The edge ditch should be made as deep as it could reach, but the rest of the digging only nine feet. The center digging is discontinued in the last few feet of the north line as the shovel is then backed up against the building beyond the driveway, and turns to get in digging position on the west line. Whether this corner could be cut square would depend on the length and tail swing of the shovel, but in general, it could not. In any case, it could not be squared to full depth.

The west line is ditched back to the sidewalk, with some additional material moved from the center as in (C). The hoe can

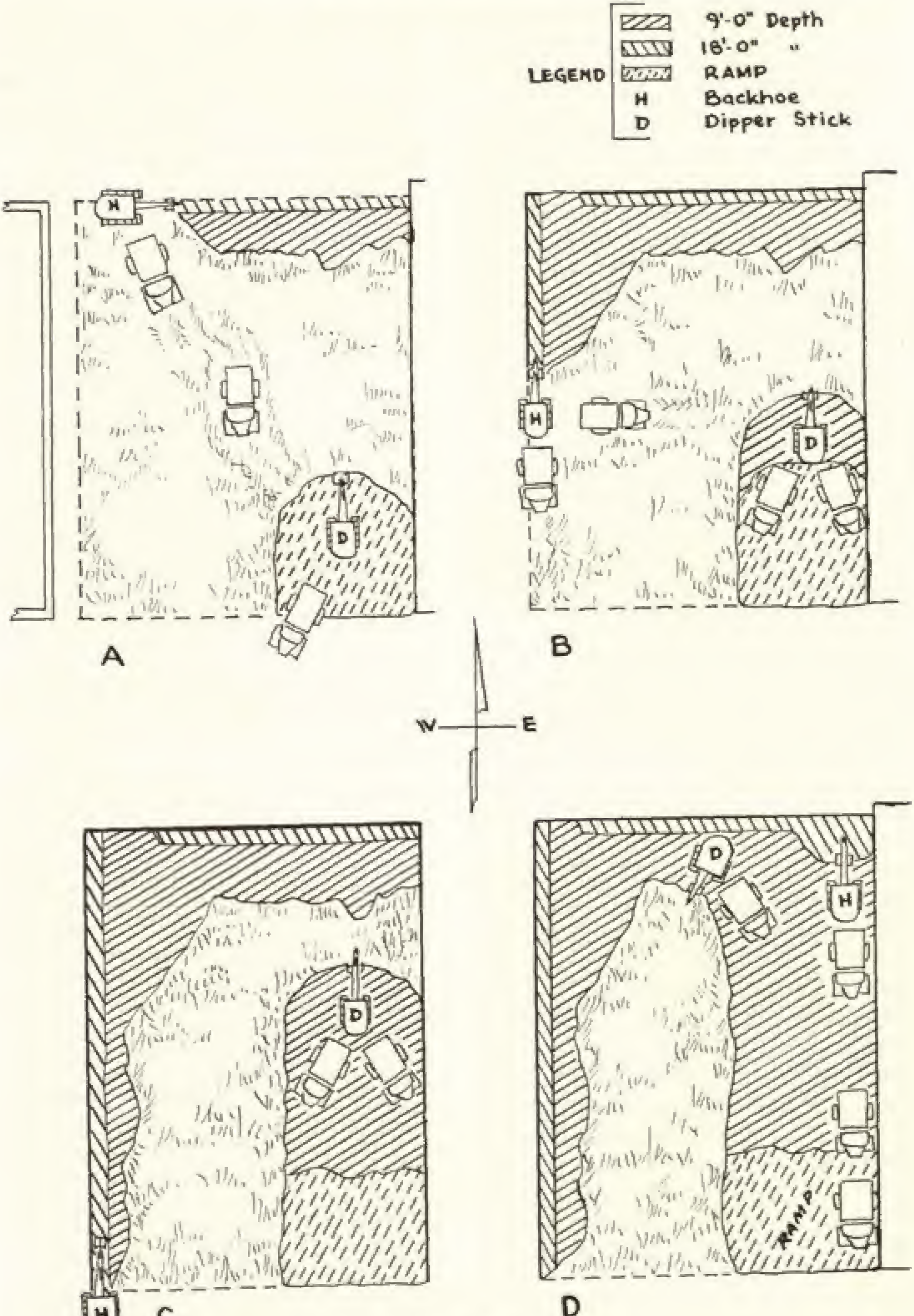


Fig. 4-23. Teaming dipper and hoe

then work a wide cut back from any convenient starting place, taking care that its efforts, combined with those of the dipper stick below, do not cut off its exit.

The trucks carrying the spoil from the hoe may be loaded sideward to the shovel for safety, or from the back for convenience. If the body sides are very high, loading will be inconvenient and spillage excessive. This difficulty may be reduced by loading directly behind the shovel, so that it will have to walk over the spilled material, which will raise it so that loading will be easier. This spillage needs some manipulation to make a smooth ramp, particularly if the soil contains boulders.

Another method of loading trucks easily would be to start the cut at the sidewalk, making a ramp down for trucks wide enough so that a truck could be backed against one part of the face to be loaded, while the hoe digs beside it.

When the combined efforts of the shovels have removed enough of the top cut so that there is room for both of them on its floor, the hoe shovel may be moved down to do the digging to final grade, while the dipper completes the upper cut, as in (D). Both shovels will be working on the same floor, but one will be digging material above, the other below. When the upper layer is finished, the dipper will leave the job to be completed by the other.

The hoe will move from ten to thirty percent less dirt each hour than a dipper of the same size, a loss which may be only partly compensated by the straight wall cuts and the ability to take away the ramp without calling in another shovel or rig. However, if certain difficulties develop, the pull shovel output will be unaffected, while that of the dipper will be sharply reduced, and the presence of the hoe is insurance against undue loss of time from such causes.

GROUND WATER

The most common difficulty is ground water. It may be in the form of springs or underground streams, or a nearly stagnant water table with capillary water moistening the soil for several feet above it. Wet soils usually turn to mud when loaded or disturbed and impede or bog down trucks.

If the first level should have a firm floor, but water be encountered in the next layer, trucks would not be able to operate on the bottom without expensive aids, so that removal of this bottom layer with a dipper stick would be impractical. The hoe would not be bothered unless there were sufficient water to hide the bottom, in which case it would have to be pumped out. Special dangers connected with such pumping will be discussed below.

Information about underground conditions may be obtained from test borings or pits on the site; from people who have dug cellars or ditches in the neighborhood, and from geologists. Such data may predict with reasonable accuracy the depth at which mud, water, loose sand, or rock might be expected, and digging plans made accordingly.

Special conditions might require taking off the ground in three cuts, or in one. The pattern should be such that the maximum amount of dirt would be dug by dipper sticks, on floors which permit trucking. When thin cuts are made the dipper can load trucks standing on the upper level, but the extra dumping height slows the digging and in some materials the bank would not be stable enough to support trucks.

Under wet or sandy conditions the bulk of the digging may be done by a dragline. If the soil is soft, a three quarter yard might possibly cut to the eighteen foot depth, but for firm or hard soils, a very large machine would be required. The efficiency of a dragline would be greatly increased by ditching the north and west walls with a hoe or a clam, and working the drag back from these edges to reduce the amount of trimming required.

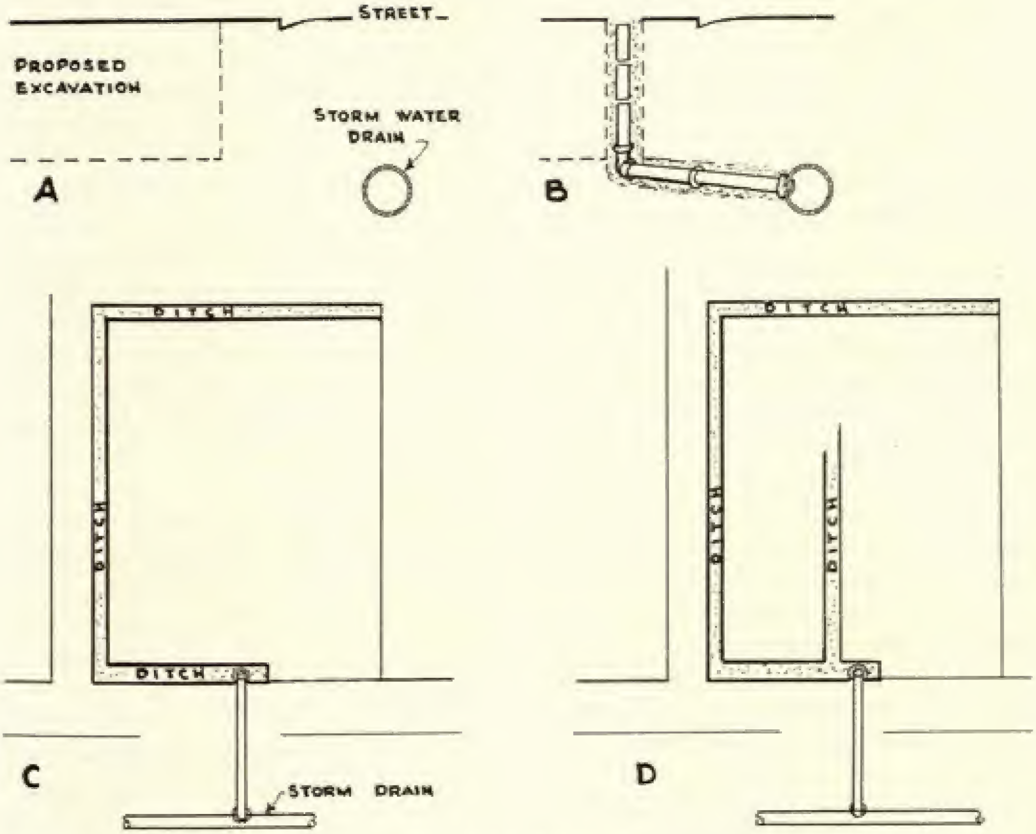


Fig. 4-24. Drainage

Drainage. Mud can be dried by draining or pumping the water. If the storm water drain in the street is sufficiently low, arrangements should be made to connect with it before excavating. A ditch is dug from the pipe line in the street to a spot several feet inside the excavation area, and a pipe with sealed joints laid, opening into the storm drain. At the cellar end, a vertical pipe of tile or concrete sections with unmortared joints or a perforated pipe is erected, as in Figure 4-24 (A) and (B). Sand or clean gravel is placed around the vertical pipe as the trench is backfilled, or a wooden barrier is placed to prevent backfill from closing the hole around it.

Each floor made during the digging should be sloped to drain to this pipe, which can be opened at any level.

This installation will also serve to remove some ground water from the site, before excavation.

A general lowering of the water table may be obtained by ditching on the three open sides, as in (C), or ditching the center also, as in (D). The edge ditches make the digging easier but the interior trenches complicate it. Heavy wood mats are required wherever shovels or trucks cross them, and these are expensive to build and a nuisance to handle.

If the storm water drain is not low enough to be useful, similar ditches may be dug and connected with a piped or open sump from which water can be pumped to a catch basin in the street.

An overloaded storm drain may push water into an otherwise dry excavation,

unless a check or shutoff valve is provided.

Well Points. A satisfactory but expensive way of predraining the area is to use well points, which are discussed in the next chapter. Points may be driven outside of the digging line on the north and west, and probably, by special permission, in the sidewalk. Seepage from the east might be blocked by the building. If not, arrangements should be made to put well points in its basement.

Open Pumping. Digging may be done without predraining and water pumped out of the hole as it appears. If the water is very dirty, and quantities are small or modderate, a diaphragm pump should be used. If the inflow exceeds the capacity of a diaphragm, about 1,500-3,000 gallons per hour, several may be used. More often, in holes of this size, centrifugal pumps are employed. Best results will be obtained by locating centrifugal pumps as close to the water level as possible, as their push is more efficient than their pull. Holes should be dug so that the inlet will be a foot or more below the water surface. Sucking air in shallow water may be reduced by floating a piece of board over the inlet, where it will block the formation of whirlpools which would conduct air down to the inlet center, or by arranging the hose so that it rises vertically out of the water.

Pumping may be done on a 24-hour day basis, or only during or just before digging operations. If pumps are to be shut down overnight and holidays in very wet holes, it may be wise to take them up each time, or to put them on floats for protection against unexpected rises in water level. Other equipment should be moved up to a safe level when work is shut down at the end of the day.

Caving. Caving of banks and undermining of adjacent structures must be guarded against, particularly in connection with pumping. Caving banks involve hazards to men and equipment, and to adjoining structures, and increase the amount of excavation and backfill necessary.

Some materials, such as dry sand, will not stand in vertical walls, and digging must be figured to include natural slopes from the foundation line outward to the surface, or provision made to drive sheeting, or erect other barriers, to hold it from sliding. Sands or sandy soils containing the right amount of moisture will stand vertically, but they cannot be trusted, as drying will result in surface disintegration and sliding, and heavy rainfall may increase their weight and undermine them by washing grains out at the bottom so that massive caving will follow.

Silts, clays, and loams usually stand well, if not too wet, but if resting on a saturated layer draining into the excavation, may be undermined so as to fall. Vibration of machinery or street traffic may cause clay to creep or flow.

Gravel may stand or may slide, depending on the shape and grading of the coarse particles, presence of cementing material, and the amount of fines. Angular gravel of several sizes, with just enough fines to stick it together, will stand wet or dry unless subject to excessive water flow, or wave action. Very clean gravel, particularly if it includes a large proportion of cobbles and rounded pebbles, may slide in much the manner of dry sand.

Causes of Caving. Danger of caving continues for days, or sometimes weeks after the cut is made. In its natural state the soil is in both static and dynamic balance—static because of inertia and the manner in which its particles are fitted and stuck together, and dynamic because the weight overlying soil or structures exerts a sideward as well as a downward thrust, which is met by equal counter thrusts from surrounding soil on the sides and below.

When a cut is made, the soil pressure toward it is balanced only by the soil inertia. This may hold it permanently in

place, or the pressure may deform the soil and cause breaking apart and rearrangement of its particles, gradually weakening it until it falls. The effect may be likened to the collapse of a building under the weight of snow on its roof, which may occur hours or days after the storm and even after part of the snow is gone.

Ground water is very effective in both holding and bringing down banks. While in very thin films it serves as a glue or binder. In contact with clay minerals it forms a lubricant, making it easier for particles to change position in response to pressure to such an extent that certain plastic clays will flow slowly. In larger quantities, water will seep or flow through the soil, carrying fine particles with it and cutting minute channels that weaken the structure. The flow of water is much slower through soil than through an open ditch, and it exerts pressure proportional to the restriction of flow.

If the water is allowed to stand in the excavation at its natural level it will cease to carry particles out of the bank, and will exert a back pressure against the bank that will tend to hold it in place. However, this will not prevent the part of the bank above water from creeping under soil pressure or absorption of capillary water, and wave action set up by wind or dropping of stones or clods will cut into the bank at water level and undermine the top.

In general, where unstable soils or abundant ground water is expected, open excavation should not be done until preparations have been made to build walls immediately after its completion; and if construction is delayed, it is better not to keep it pumped dry.

Side Effects of Dewatering. Often the most serious aspect of removing water from an excavation is the effect on adjoining property. Water makes up a substantial part of the bulk of some soils, and its removal, together with any soil it carries, sometimes causes shrinkage, with settlement of the surface and overlying structures. Damage to structures may also be caused by creeping of plastic soils from beneath them into the pit.

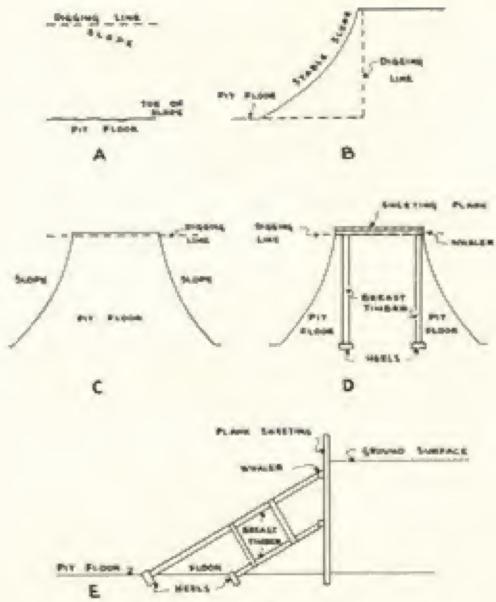


Fig. 4-25. Bracing

SHORING

Wall Bracing. Movements of soil into a pit can almost be stopped and water intake reduced by the use of timber bulkheads or sheet piling. These are required by law in many cities, and are often good, although expensive, insurance against costly repairs and underpinning.

Installing such bulkheads is a highly technical operation, involving knowledge of soil behavior, engineering calculations, and skilled personnel. There is sufficient space available in this volume for only a brief sketch of general methods.

Bracing Stable Soil. Figure 4-25 illustrates installation of thorough bracing in an excavation where a short section of face will stand for a while without support. A long section is cut back by the shovel to a slope which is expected to be stable, (A) and (B). Then a short section, perhaps ten

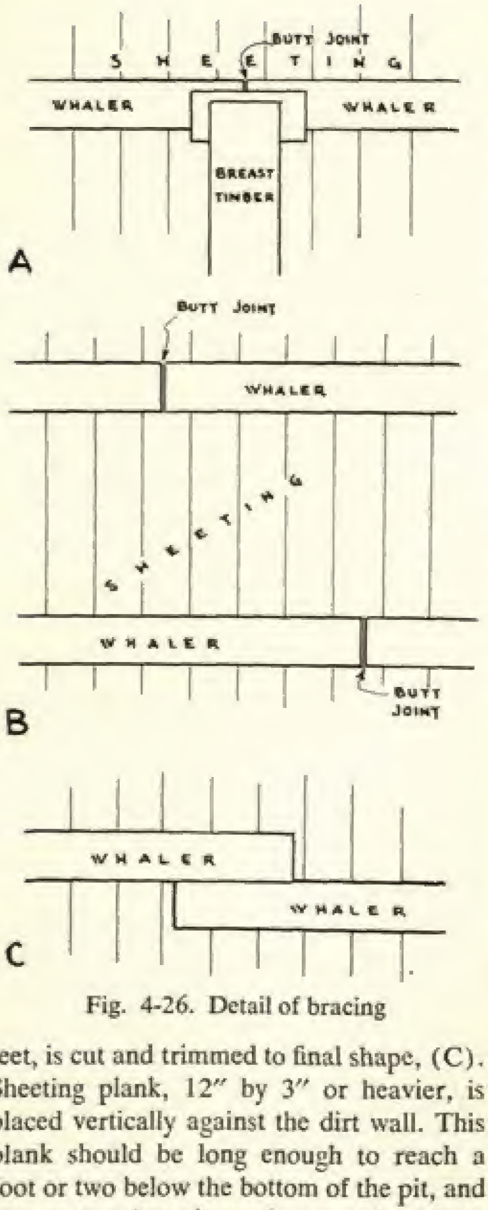


Fig. 4-26. Detail of bracing

feet, is cut and trimmed to final shape, (C). Sheeting plank, 12″ by 3″ or heavier, is placed vertically against the dirt wall. This plank should be long enough to reach a foot or two below the bottom of the pit, and one or two feet above the ground surface. Bottom penetration may be obtained by ditching, or by driving the planks down with an air hammer fitted with a special head for the thickness of plank used.

Horizontal timbers, called whalers, are placed along the face of the sheeting, being temporarily supported on cleats nailed to the planks. The whalers should be 6″ x 6″ or larger, and should not be more than five feet apart vertically.

Beams or plank mats called heels are placed on firm, undisturbed soil in the pit floor, sloping down toward the wall. These are used as abutments to take the thrust of the breast timbers that extend from the heels to the whalers. These should be 10″ x 10″ or larger. Each whaler must have two or more breast timbers, spaced five or more feet apart. If the heels are firm, the spacing of breast timbers can be increased by using heavier whalers.

While this bracing is being installed, an adjoining section of the wall is trimmed. This is braced in the same manner and the work continued in successive sections.

The sections may be tied together in several ways. The breast timbers may be placed against the whalers where they are butted together, as in Figure 4-26 (A), with or without the plate shown. The joints in different whalers may be staggered, as in (B), or may be overlapped, as in (C).

Nailing is kept to a minimum to avoid damage to the lumber. The bracing is dismantled after the foundation is placed and the material removed for re-use. The sheeting is usually pulled by a crane or pile driver equipped with a special clamp for gripping the top of the planks.

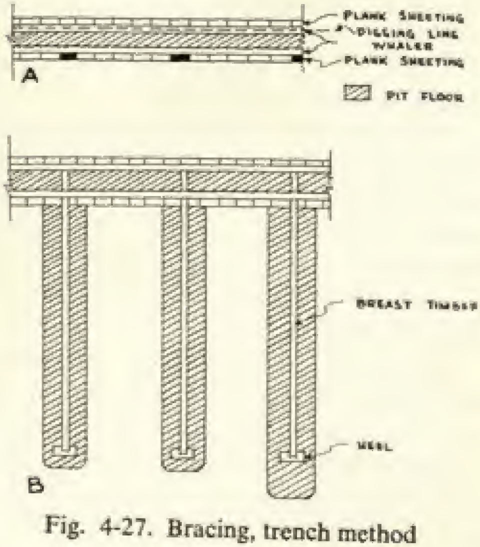


Fig. 4-27. Bracing, trench method

Unstable Face. If the soil is so unstable that it cannot be trusted to stand even in short sections, the sequence shown in Figure 4-27 may be followed. A trench is dug with the outer edge at the digging line. This is braced with sheeting, whalers, and sheeting jacks in the manner described in Chapter 5, except that planks are left out of the sheeting on the inner wall at regular intervals.

Additional trenches are now dug into the excavation at right angles to the edge ditch. Heels are placed in them at or below floor level, and breast timbers run from the heels to the whalers on the out wall, through the spaces in the inner sheeting. The dirt between the breast timbers is now dug out, usually with a clamshell with laborers assisting, and the sheeting jacks and inner wall bracing removed.

Steel piling may be driven along the digging line instead of digging the braced ditch. The breast timber ditches are dug in the same manner as described. A ditch is then dug on the inner side of the steel piling, and a whaler and breast timbers placed. Digging is then carried down to the level of the next whaler, which is placed and braced.

Steel piling does not require as close spacing of the whalers as wood sheeting. A single whaler near the top is often sufficient, and in some cases it is not braced at all.

Cofferdams. When dry excavation is carried a considerable distance below the water table without dewatering the area, the heavy walls constructed to keep out soil and water are called cofferdams. The bracing structures already described can be included in this term.

Cofferdams consisting of a single row of interlocked steel piling, with interior bracing, have been used for depths up to 60 feet, although ordinary practice limits them to 40. They may be installed by hammering the piling in undisturbed ground until it reaches bedrock, or to sufficient depth below the excavation floor to be considered safe. All the sections should be placed and driven to moderate depth before any of them are driven all the way, to make sure that all joints interlock properly.

Excavation is likely to be done by clamshells. Bracing is placed against the inside of the wall as it becomes exposed.

If the soil is very porous, great difficulty may be experienced getting the water down the first few feet, as the joints between sections leak quite freely until forced together by water pressure. More or larger pumps may be used at this stage of the job than at any later time. It may be necessary to trench outside the wall to place a clay seal part way down, or to partially seal the soil with cement grout.

Porous soil under the bottom of the wall may permit excessive quantities of water and sand to boil up in the bottom of the excavation as final grade is approached. If the bottom is in clay, but porous soil is immediately below, the job may proceed easily, and then suffer from a sudden and disastrous blow-up of the bottom.

The double wall cofferdam is a more elaborate structure, which provides means to combat the problems encountered, and to work at greater depths. Two rows of steel interlock piling are driven. The space between them may be excavated wet, and the bottom concreted to form a good seal against a rock bottom and to protect the ends of the piles from being bent in a blow-in by water pressure. The walls may or may not be cross braced to each other. They are filled to the top with clay or other soil.

An area protected by a cofferdam may be dug wet, in which case the structure serves to prevent soil from slumping into it.

Caissons. A caisson is a structure which serves to keep soil and water out of an excavation, and forms part of the perma-

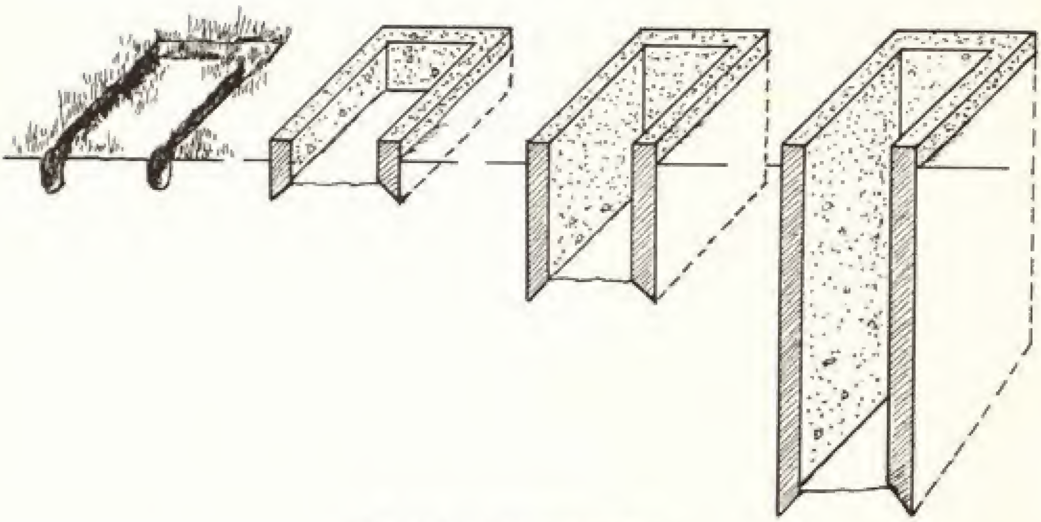


Fig. 4-28. Sinking a caisson

nent structure for which the excavation is made.

A simple type of open top caisson, and stages in its growth, are shown in Figure 4-28. A hollow square, ring, or other shape is made of reinforced concrete, with the bottom tapered to an inside edge. If the work starts on dry ground, it may be built in a shallow excavation where it is to be used. If the start is under water, it is made elsewhere with walls high enough to keep out water when it is lowered into place. Transportation is usually by barge.

The caisson is lowered by digging inside to undermine it, and building the top to provide more weight, and to keep it above ground or water as it descends. Most of the digging is done underwater, and it is a very ticklish job to do it accurately enough so that the caisson will sink straight. When it comes to the bottom, investigation must be made to determine whether it is on bedrock or boulders. If the rock surface slopes, concrete must be pumped underneath to give it firm bearing on the low side.

The pneumatic caisson has an air tight cap over the bottom, with sufficient air pressure maintained under it to keep water out. Air locks and chambers are provided for entrance and exit of men and material. Much of the digging is done by hand, and in deep work at high pressures men may be limited to less than an hour of work at a stretch, with long periods spent in entering and leaving the high pressure work chamber. Depths up to 100 or 110 feet can be reached.

Pneumatic caisson excavation is extremely expensive, but it is more positive in results than the open top method. It is the only practical procedure in ground which is very irregular in structure, or which contains boulders, tree trunks, or old piling.

ROCK

Bedrock. If bedrock is encountered that is too hard for the shovel to tear apart it must be blasted. Generally it is best to complete the earth excavation first, to reveal the full extent and as much of the grain and quality of the rock as possible, before going to work on it.

Sometimes, however, drilling and blasting are started as soon as the rock is found, and the shovel doing the earth excavation can be utilized for handling logs or blasting mats. This may save shovel time, as under city conditions it is not often practical to blast rock fast enough to keep a shovel

busy, and a shovel whose only duties are handling mats and removing blasted rock is likely to be idle most of the time. On the other hand, earth hauling trucks will be stopped while the shovel places mats and during blasting.

Hoe shovels and small dozers are good machines for cleaning the bulk of earth off ledges, but there is almost always need for hand work also.

Procedures for the rock blasting and removal are outlined in Chapter 9. However, it should be emphasized that blasting near streets and buildings is a much more dangerous and specialized job than the same work in a quarry or a country highway cut. Elaborate precautions must be taken to prevent material from flying, and large blasts, or small blasts following each other quickly at regular intervals, must be avoided because of danger of concussion and vibration damage to nearby buildings. Jobs must be inspected in advance by the insurance company in order to set a rate in line with the risks.

Boulders. The presence of boulders slows digging. If they are numerous and of such size that they must be lifted individually by chains, or broken up before handling, they may be more expensive to dig than a uniform mass of bedrock.

Clamshell, and more particularly orange peel buckets, handle boulders up to the lifting capacity of the shovel very readily. If they are not available, chains, cables, or slings may be used for stones too large or misshapen to be handled by a dipper or hoe bucket.

Chains should be of the lightest size that will lift the weight, as a thin chain grips rock much more closely than a thick one. Undersize chains break frequently, and spares and repair links and hooks should be kept on hand.

Alloy chains are expensive but are small and light in proportion to strength.

Small cables grip rock well but wear and

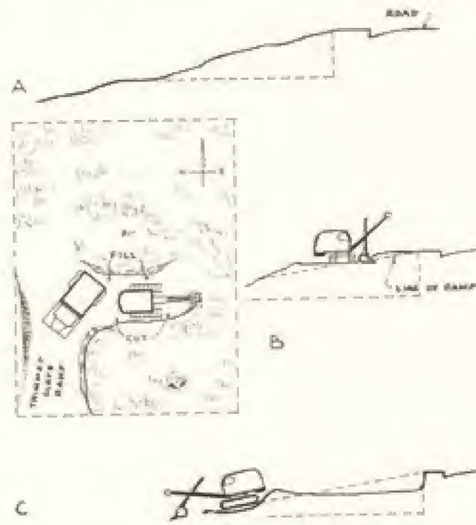


Fig. 4-29. First cut in a down slope

fray rapidly, so that sharp ends of broken wires make them dangerous to handle.

Slings may be made of several strands of light cable or chain, and combine the grip of small sizes with the strength of large ones.

Boulders may be broken by blasting but in city areas mud capping is not permissible. Splitting may also be done with sledge hammers, air hammers, or drills and plug and feather sets.

HILLSIDE SITES

Downslope. So far we have considered excavation in a level plot. As the cellar depth is calculated from street or sidewalk level, a downward pitch to the rear would decrease the amount of excavation, and an upward one would increase it.

If the lot slopes down to the north, as in Figure 4-29, the natural grade can be cut to the proper slope for a ramp by a bulldozer, and the material removed used to build a flat shelf at the first cutting level on which the shovel and trucks can start work. If insufficient dirt is cut in making the ramp, the shovel can dig into the hill and sidecast below, to build it up to the desired size.

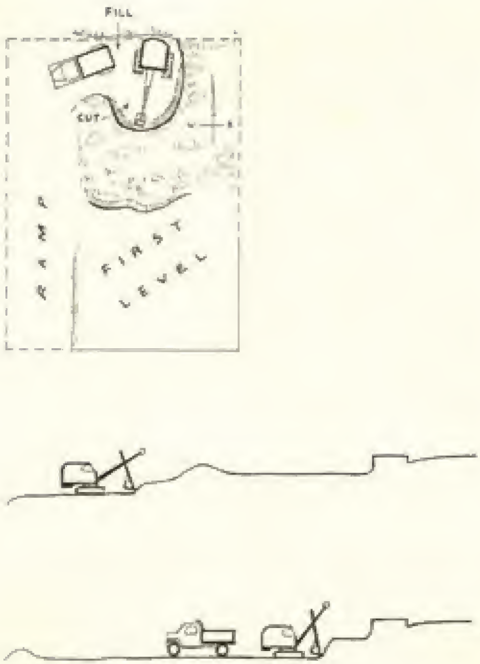


Fig. 4-30. Second cut

Excavation is carried back to the side of the ramp and to the south and west digging lines, in any convenient manner, while the bulldozer shapes the bottom level, making a flat space as before.

When the shovel starts work at the bottom, Figure 4-29, the excavation and ramp removal are carried out in the manner described earlier.

If two shovels are used, one can work on each level. The upper one should work across to the east side and finish it first, so that the one on the lower level can work in without cutting it off.

It is unlikely that a back hoe would be used on such a job, except in removing the ramp, unless mud conditions are encountered. Sometimes soft footing can be economically handled by surfacing the truck road with gravel, crushed stone, or dry fill.

Bottom Access. It may be possible to arrange for the movement of machinery and trucks into the lower end of the lot, as in Figure 4-30. A bulldozer may then cut a truck road and turn around into one side of the lot. Loaded trucks will now move downhill and maximum loads can be carried.

It may be difficult for the empty trucks to turn on the slope and to back uphill, particularly in sloppy going. If the shovel first digs a wide shelf as in Figure 4-31, the trucks can turn on it, and another roadway can be graded later for exit so that no uphill backing will be necessary.

Cut and Fill Digging. Figure 4-32 shows the same sloping lot with a retaining wall built along its back lines. The spoil from the cellar is to be used to fill up to this wall for parking area.

A dipper shovel and trucks may still be effectively used for the digging, but the short haul makes possible the use of other machines.

However the soil is moved, it should be

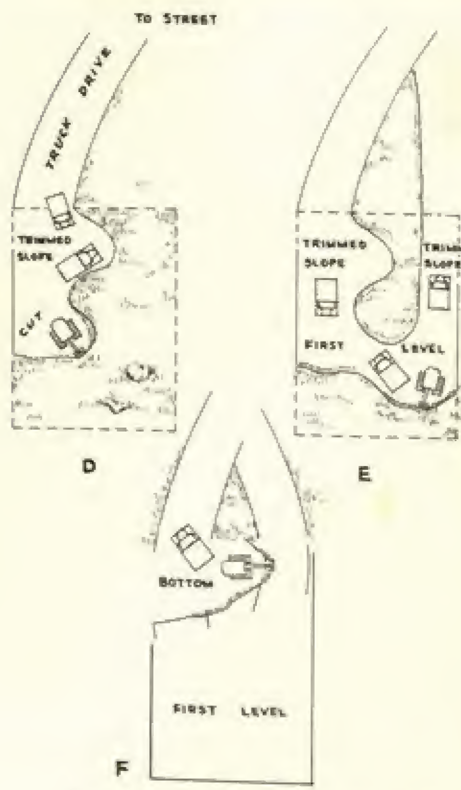


Fig. 4-31. Slope with rear access

spread in thin layers and thoroughly compacted by rolling in open spaces, and tamping where rollers cannot reach. This will prevent serious mud difficulties during the work, possible damage to the retaining wall from pressure or fluid mud after heavy rain, and excessive settling of the finished fill.

The average length of push is about one hundred and twenty feet, very slightly downhill. This is within the economical range of medium to large bulldozers, or small scrapers, but assistance will be required from a dozer shovel or hand labor to cut out the south corners. The equipment should be small enough to leave by the driveway when the job is done.

A dozer first cuts a shelf, level or sloping opposite to the hill at the top, just below the sidewalk. This is done by digging along the edge line until a bladeful is obtained, then turning downhill, lifting the blade at the same time, so that the fill is built higher than the cut to allow for compaction. Pans (scrapers) can be used to cut down this shelf as soon as it is a few feet wider than they are, but a dozer will be needed to keep the walls trimmed back to a vertical. The dozer can also cut much further into the corners than the pan by the process of gouging and then swinging out.

The dozer shovel can square the corners by working against one side, parallel to it, and digging into the bank until the other side of the corner is reached. The spoil is picked up, moved back, and dumped in the path of the pans. Best work can be done if the corners are kept cut down within a few feet of the level on which the pans are working.

The scrapers may be kept moving in a rotary path, as in Figure 4-33 digging at the south end, and dumping and spreading along the retaining wall. As the fill rises, it will enlarge to the south. At the same time, a bulldozer can be working down the center section in the soil to be moved the

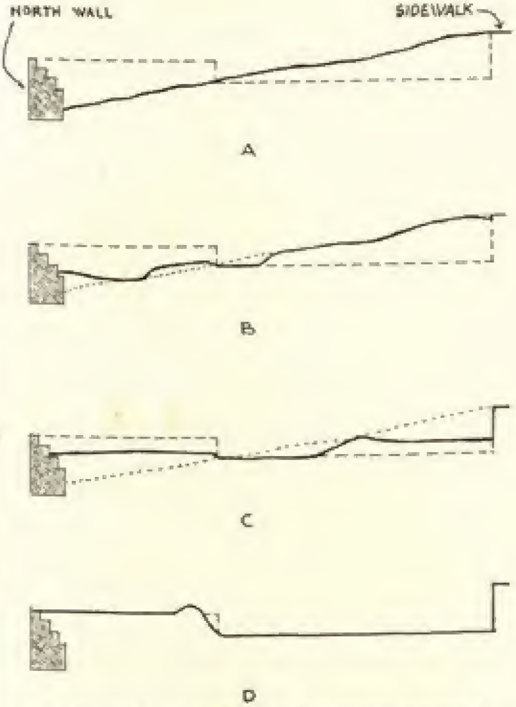


Fig. 4-32. Filling against retaining wall

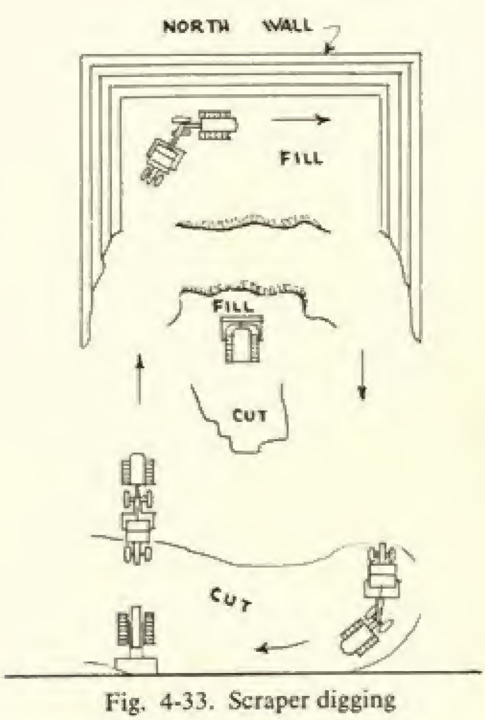


Fig. 4-33. Scraper digging

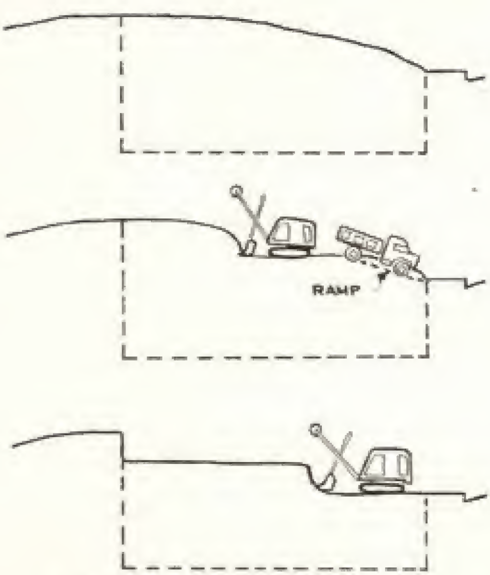


Fig. 4-34. Cellar digging in a hill

shortest distance. This dozer may also take care of trimming the fill for the pans and pushing it into the corners.

A tractor-drawn sheepsfoot roller should be kept moving over the fill in both pan and dozer sections. Hand, gasoline, or air tampers should be used along the wall.

The parking lot fill, and that needed in the rear part of the driveway, cannot be placed on the south side until the foundation of the building is in place. Material needed for this can be piled on the edge, ready to be pushed in place.

The sidewalk edge of the pit might also be cut by a clamshell standing on the sidewalk. The dirt could be either loaded into trucks or cast out into the pit in reach of the pans.

If additional fill is needed in the parking area, it should not be trucked in until the building foundation has set long enough to give support to the driveway.

Hill Removal. It often happens that the building site slopes up from the street, sometimes very abruptly. The hill must be removed, in layers if it is high enough, before digging down from the street.

Figure 4-34 shows one such situation. The first cut starts above street level so a ramp is dug up to it. When the top has been removed, digging is started at the street level, and the underground cuts taken afterward. Two or more shovels can work on the job, usually on different levels.

The upper cuts should be sloped so as to drain toward the street, but not steeply enough to cause gullying and washing of dirt onto the street, as the contractor is responsible for any damages caused by the work.

CHAPTER FIVE

DITCHING AND DEWATERING

DITCHING

Drainage by ditching is a very ancient type of excavation, and even drainage tunnels were built in prehistoric times. The purpose of this work was generally reclamation of land for agriculture.

Modern advances consist largely in the use of machinery for ditching, some improved types of pipe, and use of pumps to dewater areas that cannot be readily drained by gravity flow.

The most important dry ditching machines are hoe and clamshell attachments for revolving shovels, and whee. and ladder type ditching machines. In soft swamps, draglines are the preferred tool. Dipper sticks, draglines, graders, and bulldozers may be used for shallow trenching in the dry.

A bucket used in cutting narrow ditches should be wider at the cutting edge than at the back, either through taper of the sides or attachment of side cutters, so that it will not bind between the walls of the ditch.

BACKHOE WORK

Ditching with a hoe (dragshovel) is easiest and neatest if the ditch is the same width as the bucket cut. This permits the machine to stand over the center line with the tracks parallel to it, as in Figure 5-1 (A), and dig a straight sided ditch by peeling the dirt off in layers.

When the desired depth is obtained along the space the shovel can reach, it is walked away from the ditch from two to twelve feet, and a section of that length excavated. Short moves are made in connection with deep ditching, cutting the bottom to an exact grade, or cutting curves; longer moves are feasible for rough shallow work.

Curves. Curves are dug as a succession of short, straight ditches but a skilled operator can bevel the edges to produce a smooth curve. The machine stands with its center a little outside of the center line, and digging is done in the outer half of the bucket reach. Moves are short.

Angles. Many kinds of pipe require laying in straight lines and angles rather than curves, and trenches in which they are to be placed are dug accordingly. Angles are made by digging slightly past the angle point, then shifting the shovel to straddle the new center line, as in (B).

Spoil Piles. Spoil from the ditch is usually piled on one side, far enough back to allow a footpath or working space between it and the ditch. If a large volume of dirt is being moved, the pile must be

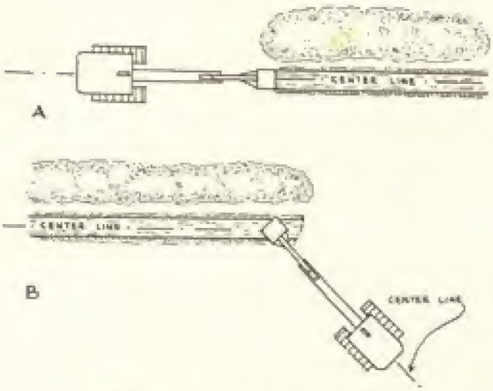


Fig. 5-1. Lining up a hoe

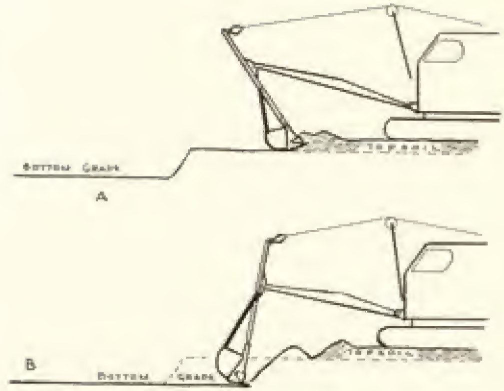


Fig. 5-2. Separating topsoil

pushed back by the bucket as it is built, and, in addition, it may be necessary to allow the spoil to come to the edge. Piling on both sides is usually avoided because of backfilling work. It does serve to block off the ditch so that people are less likely to walk into it absentmindedly or in the dark, although it is not adequate barricading.

Topsoil. If topsoil is to be saved and put back on top of the other fill, it may be piled on the opposite side of the ditch from the deeper digging. If the volume of the spoil is not large, the topsoil may be placed on the same side as the fill, but farther back, so that when a dozer backfills, the topsoil will be next to the blade and will reach the ditch after the fill.

Topsoil is salvaged during the digging by scraping it off first, and bringing the bucket as near the shovel as possible on the last bite. The body of the ditch is then dug, with the bucket lifted out short of its closest position. There should then be a foot or two between the ridge of topsoil and that of fill, as in Figure 5-2. When the shovel backs away, it can dig the pile while stripping the next section.

Sod. If sod is to be saved, it should be removed ahead of the shovel. It may be dug by hand, or cut in strips by a tractor or horse-drawn sod cutter. The strips of loose sod left by a cutter may be sliced in sections and lifted and piled well back by hand. Sod should be removed at least six inches, and preferably a foot, back from the digging side lines to avoid damage.

Guides. Sod removal serves as an excellent and unmistakable indication of the location of the ditch, otherwise a line of pegs low enough to allow the shovel to walk over them may be used. The shovel is lined up over the ditch in the same manner as described for cellars in the previous chapter, except that if digging is done to a center line, center marks must be placed on the dead axles.

Side Digging. A hoe should be worked away from the end of the ditch that is blocked. In ditching from a house to the street, it starts at the house and finishes in the open space of the street. However, it often happens that a ditch must be dug between two buildings, or under other circumstances where both ends are blocked.

The simplest method of accomplishing the necessary turnaround is to dig the ditch from one end, then from the other, having them meet at some spot where the shovel can move off to the side. The digging of the second section should be stopped while there is still comfortable room to turn the shovel and get it out, as in Figure 5-3 (A). The shovel is then turned at right angles to the ditch and walked back into the undug space, with its center pin in the center line of the ditch, as in (C). It then digs as close to its tracks as possible on both sides and backs away, connecting the ditch sec-

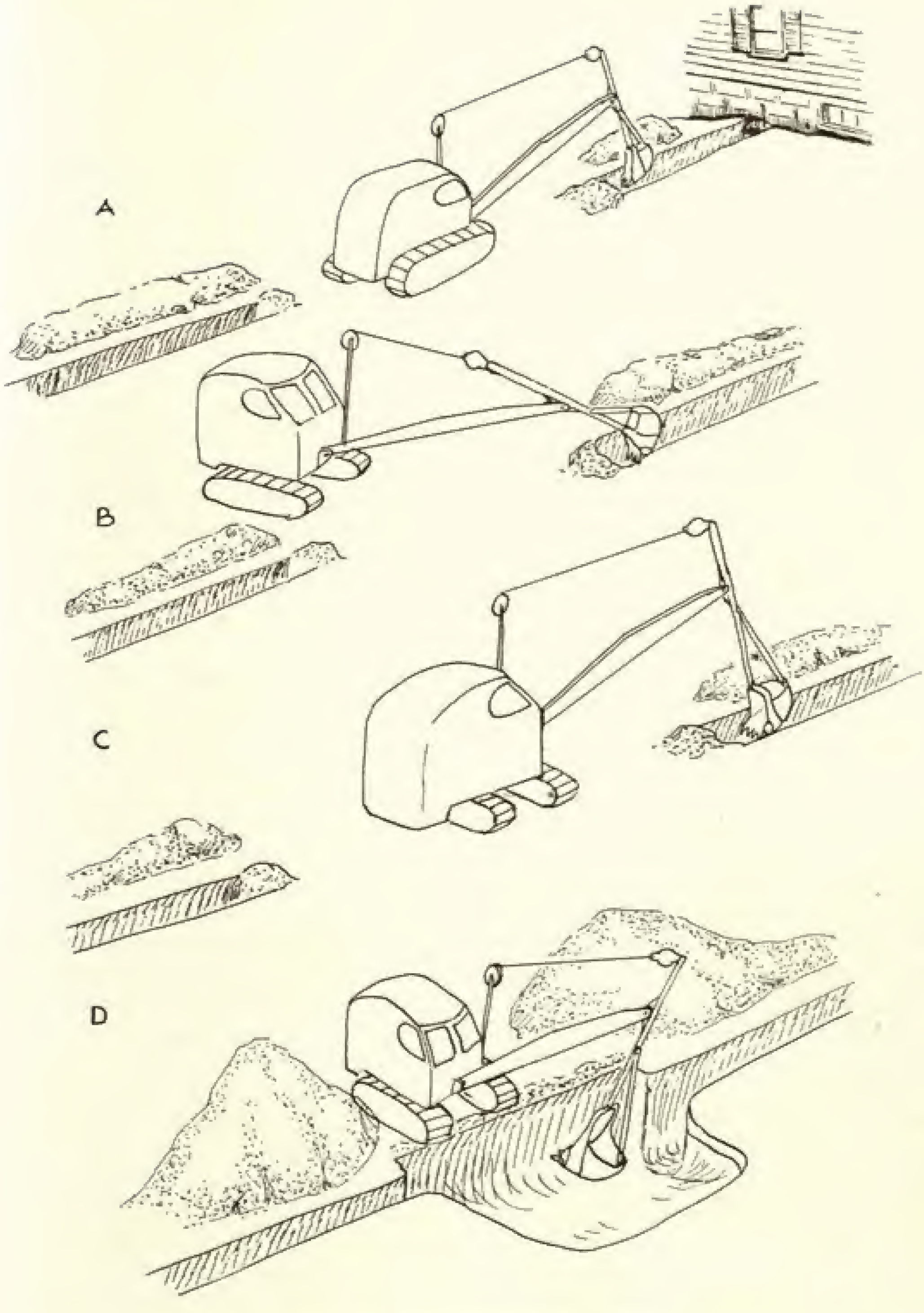


Fig. 5-3. Connecting trench sections

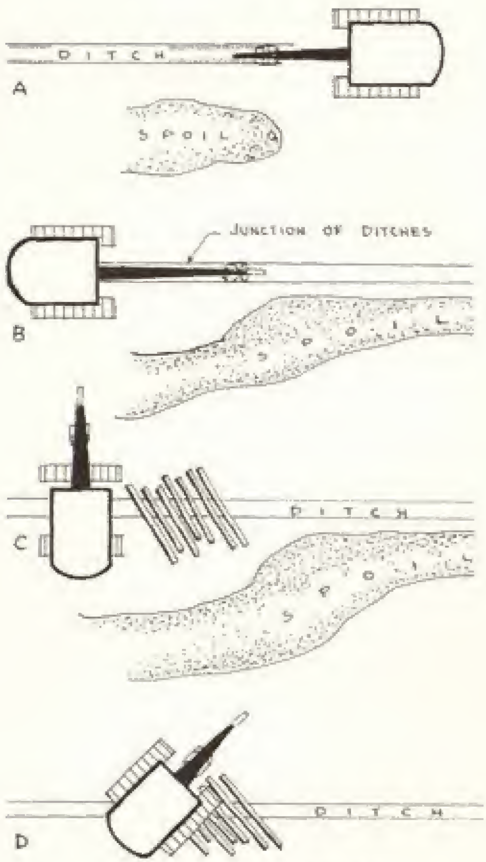


Fig. 5-4. Overlap method

tions by digging at right angles to them.

This method involves making a connection which is very wide in proportion to depth, and is therefore wasteful of machine time, unless a spot is chosen where use can be made of the width, as in building a pump house or manhole.

Overlapping. If the soil is firm and the ditch narrow, the ditch may be overlapped. In Figure 5-4 (A) the shovel in digging the first section of the ditch has piled the spoil well back from the edge. It then can start at the opposite end of the ditch and cut until it is connected with the first section, which it straddles for the last part of the digging (B). Logs or beams are then placed across the ditch, as in (C), and may be cut down into its sides. Railroad ties are excellent for this job. The shovel is then turned so that the track next to the spoil pile will walk across the ditch on the beams. This turn may be sharp to increase the bridging action of the track itself and reduce weight on the beams; or it may be gradual to reduce danger of caving.

If the ditch line includes an angle, the crossing should be made there as it enables the shovel to walk across with less turning.

Wide Ditches. When a ditch is to be more than one bucket width, one or both edges will be slightly uneven because the bucket will move inward, toward the center pin of the shovel. Usually one side is made straight by lining the shovel to that side, and the hacking done on the other side. If neatness is important, the ridges can be smoothed by drawing the bucket in while lightly swinging against the edge.

The full width of the ditch should be taken off in layers if it is to be dug from one position, rather than cutting one side to depth then starting on the other.

A ditch with two straight sides may be made by lining the hoe up to cut one straight side, and completing digging that can be reached from that position. The shovel is then moved back and maneuvered into position to cut the other edge straight, repeating this operation with each backward move. This works best when the ditch is two or more bucket widths.

If sloping beds of shale are encountered, digging should be arranged, if possible, so that the bucket teeth will cut along the bedding planes, as in Figure 5-5.

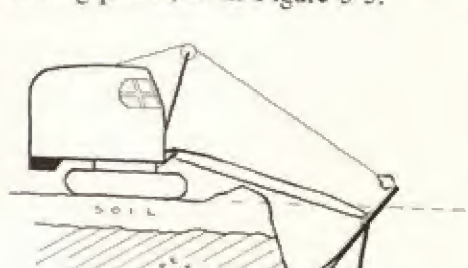


Fig. 5-5. Best angle to dig shale

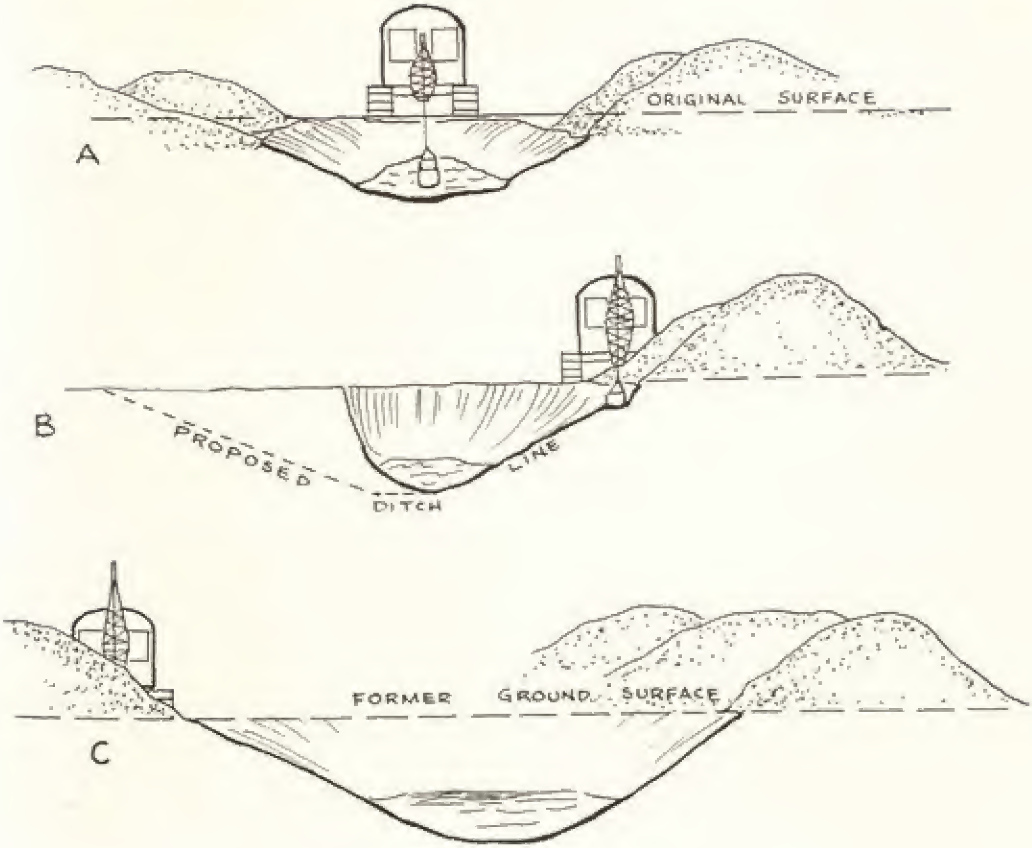


Fig. 5-6. Wide dragline ditch

Shale dug in this manner at moderate depths is apt to come up in sheets so that the ditch will be widened irregularly.

Production. In shallow trenches with spoil piled at one edge cycle time is fast, 15 seconds or better, but the bucket fills poorly and frequent moves take time.

In narrow ditches yardage per foot is less but bucket efficiency is low. In deep work the bucket fills well and moves are infrequent, but the cycle is slower.

In good ditching conditions, the hoe may move from 50 to 100% as much dirt as a dipper shovel loading trucks, Figure 13-72.

Separating topsoil, digging hard soil, cleaning off rock, watching for pipes or conduits, and cutting curves and angles take longer. In soft ground speed depends on the crew setting the bracing.

OTHER SHOVEL RIGS

Clamshell. A clamshell ditches best when on the center line. If the ditch is narrow, the tagline chains are fastened to one jaw, or for a very wide cut, to both jaws. A ditch of intermediate width is made with the chains in the one-jaw position, and the soil is taken out in layers.

Connections are easily made in narrow ditches by attaching the tagline chains to both jaws after completion of the main ditching, and digging the connection from the side. Whole ditches may be done from the side in this manner, but it is harder to keep on the correct line. The side position is desirable in deepening an existing ditch, or in digging beside a wall.

Smooth curves may be dug either by frequent readjustments of the position of the shovel, in the same manner as with a backhoe, or by having a man on the ground twist the bucket into proper position by pushing it by hand or with a stick as it is about to touch the ground.

Dragline. The dragline is the preferred shovel for ditching in swamps, and for making ditches with sloped banks when the spoil is to be piled alongside. It works along the centerline of the ditch, as in Figure 5-6 (A), cutting the bottom and slopes in one operation. If the ditch is too wide for this, two cuts are made from the sides, as in (B) and (C).

If the fill is to be trucked away, a dragline or a backhoe may be used in this manner. Draglines may have difficulty digging hard earth which the hoe would move easily.

Dipper Stick. The dipper can dig trenches four to seven feet in depth from the top, or wide trenches from the inside. A neat ditch may be dug from the top by straddling it, if the soil is very firm, or if support platforms are used. Trenching may also be done beside and parallel to the shovel's path, but this involves quite a wide cut in proportion to depth and is difficult to trim.

Interior digging conforms in general patterns to that discussed for cellars in the previous chapter. Part swing shovels can dig narrower slots than conventional models, as they do not need space for tail swing, but they cannot load trucks behind them.

Comparisons. The hoe is the best machine for ditches of moderate depth and width where boulders or stumps may be encountered. It will break up heavily fractured hard rock, and soft or thin bedded shale, and dig very hard soils if the bucket teeth are long and sharp. It can dig out large boulders by widening the trench as much as necessary, and dragging them up the slope toward itself. The ditch can be easily curved around boulders too large to lift or pull.

The clam is a slower machine but is able to dig to any depth desired, and can work close to obstructions, except overhead ones. If fitted with a bucket of sufficient weight, it will dig hard soil and soft rock. It can pick up moderate size boulders in its bucket, and lift larger ones up to its capacity by chaining.

DITCHING MACHINES

Ditching machines are often preferred for use in localities where boulders are rare or lacking. They dig by continuous picking rather than by the dig and dump cycle of the shovel. They work rapidly; make a neat ditch, usually with a curved bottom which is helpful in lining up pipe; can work with less headroom and do not need space to swing. They can dig certain classes of homogeneous soft rock which a shovel cannot, and will not tear up the banks in soft shale. Buckets may be obtained in various widths, including sizes much narrower than practical for a shovel bucket. A ditcher cannot readily make a ditch wider than the longest sidecutters available for the buckets it is using, unless the boom is built to hold two sets of ladders and buckets.

Ditchers can be equipped with shoes or reels to lay tile or flexible conduits immediately behind the digging so that shoring is not necessary.

Operation of these machines is discussed in Chapter 14.

Graders and Dozers. Graders can make shallow ditches with sloped sides rapidly and neatly.

The road building processes described in Chapters 8 and 19 involve ditches which serve to produce road fill.

If a ditch is to be dug by a grader without building anything with the spoil, the same processes can be followed with the spoil cast in both directions.

The bulldozer can dig a wide, shallow trench from the side, as shown in Figure 5-7 (A). The volume of excavation required increases very rapidly with depth because of space needed for ramps.

When the practical limit for side excava-

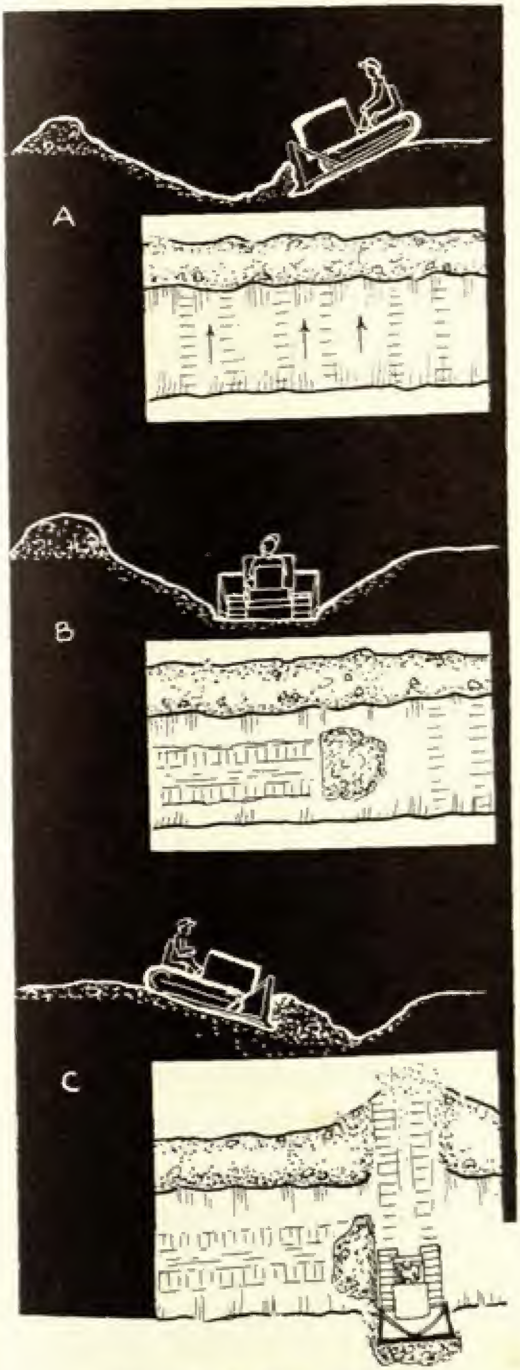


Fig. 5-7. Bulldozer ditching

tion is reached, the dozer can work in the ditch, pushing dirt into heaps, which it then pushes to the side, as in (B) and (C).

An angling dozer can excavate by side casting in the same manner as a grader, but it may be harder to keep lined up.

ROCK

Stripping. Ditches frequently encounter rock that is too resistant to be dug by the available equipment. Occasionally the line of work may be shifted, but it is usually necessary to blast.

Dirt and rotten rock are removed by conventional methods. Spoil should be piled far enough back to allow space for the drilling equipment, and for the shovel when it returns.

After machinery has removed the soil, the rock surface should be cleaned by hand. If the trench walls are liable to crumble and slide from drilling vibration, they should be shored up, even if depth is shallow.

Opencut blasting is described in Chapter 9. Trench work differs chiefly in the restricted working space, and in the fact that all shots are tight. Loading must be fifty to one hundred percent heavier than on wide faces.

Drilling. Jackhammers can be used with the operator standing on the rock, or on the ground surface beside the ditch. Wagon drills are stationed on the bank. Special ditching drills may be suspended over the work by cranes.

Several drilling patterns for three or four foot widths are shown in Figure 5-8. In each of these blasting is done back from an edge or face of rock exposed by digging, or by previous blasting.

The distance or length of ditch that can be blasted in a single shot depends on the near presence of buildings, whether it is permissible to overbreak the sides, and whether delay caps are used.

The holes next to the face can throw their burden along the line of the ditch. Any holes behind them, shot at the same time, will tend to expend more of their

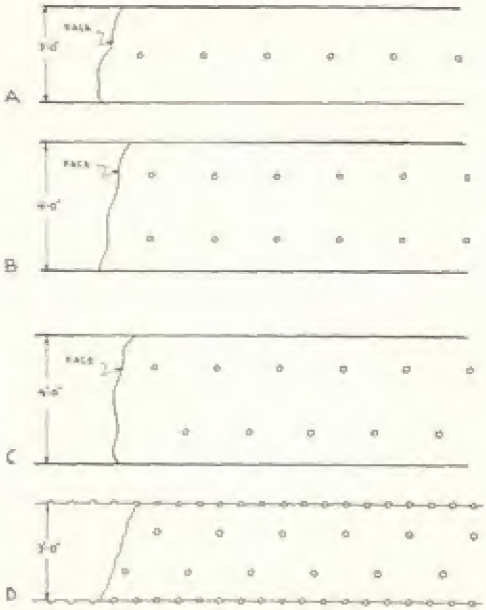


Fig. 5-8. Rock drilling patterns

energy to the side. They will, therefore, be loaded more heavily, will tend to overbreak the sides, and to produce finer crushing of rock.

Some or all of the edge holes in (D) are left unloaded. They are called relief holes, and serve to reduce overbreak, and to keep the cut full width.

Delay Caps. After the blaster has decided on the area to be blasted, the number of holes included in it may be shot at one time; or a much larger number may be fired with delay caps. The first series will be at the face, with the other two groups following in succession.

Millisecond delay caps give the best results, as they provide thorough breakage with minimum concussion. They are arranged so that the wave of explosion travels back from the face, with such short intervals between rows that each is partially confined by the force of the previous blast. This condition is favorable to good fragmentation and reduced overbreak.

Damages. Nearby buildings, or more distant installations containing delicate apparatus, may dictate the size and type of shots. The conservative procedure is to fire one row at a time, and muffle and restrain the explosion with dirt and mats. Millisecond delays may permit much larger shots because the explosion is spread over enough time to reduce its sharpness.

Standard delays permit firing a succession of small blasts with one jolt, but there is danger that they will set a periodic vibration in some building or object which will damage it more than a heavy single explosion.

Deep shots, or those well buried, produce less damage than shallow ones. If the explosion is so confined that it acts about equally in all directions, concussion is at a minimum. If any part of the force can escape rather readily, its blowout will produce a reaction or back-kick against the solid rock, which will shake the surrounding area severely.

Air waves, which are serious offenders in breaking windows, can be prevented by thorough muffling.

In any blasting near buildings, roads, or people, elaborate safety precautions must be taken. An absolute minimum is confining the explosion so that no fragments can fly, giving ample advance notice of the blast, and blocking all roads and paths into the danger area. Woven steel mats are the only safe cover for close blasting.

The contractor's liability insurance company usually requires that it be permitted to make an inspection of the job before any blasting is done. Any safety precautions recommended by the inspector should be carefully observed.

Burial. When the rock surface is well underground, the ditch may be refilled with dirt after the rock is drilled and loaded. This confines the explosion, prevents rock from scattering, muffles the noise, and protects the ditch walls from caving. It provides a safe working area for the machine, usually a backhoe or clamshell, which will re-dig the trench after the blast.

If the dirt fill is shallow, or rocky, it may be necessary to use mats or logs in addition.

Wiring must be thoroughly protected before filling on top of loaded rock. Fine dirt is hand shoveled over the connecting wires. If the rest of the fill is fine, a thin cushion is enough. If there are heavy or sharp rocks which cannot be kept out, a deep protection is required.

The lead wires may be run along the rock surface beyond the area to be filled, or led up to the surface inside air hose or other tubing.

Two caps may be placed in each hole with duplicate wiring, or Primacord can be used.

Backfill may be pushed in from the side by a dozer, or trucked from an excavator digging another section of the ditch.

Removal. Blasted rock may be dug from the trench by machine, by hand, or by both methods.

If the ditch is narrow, with hard, irregular walls, projecting stubs may jam a bucket so frequently that hand work may be cheaper. A bucket or container is frequently loaded by hand and hoisted by a machine.

Large rocks are lifted with slings or tongs.

In general, it is good policy to blast sufficient width to insure working space for a clamshell or hoe bucket.

CAVING OF BANKS

Many soils will not stand in vertical walls, so the sides of the ditches must be either sloped back or braced. A few soils will not stand on even a moderate slope, and these will require very heavy bracing.

Ground water is the most important single factor in collapse of edges of cuts. It acts as a lubricant that enables the soil particles to move on each other readily, and exerts pressure that moves the particles toward the ditch. Sand faces may fall from this cause, or from the drying action of water draining and evaporating, so that the bond between the grains is weakened.

If water is allowed to stand in a ditch, danger of caving from flow of ground water into it and from other dynamic forces acting in the soil is reduced. However, wave action set up by dropping of stones or chunks of dirt may cut into the walls and undermine them.

It may happen that the upper part of a trench wall will be firm dry material, but that a shallow layer at the bottom is waterlogged and unstable. The sides will stand for only a short time before becoming undermined by movement of the lower layer.

In general, caving of ditch sides is more apt to happen minutes, hours, or days after the digging than immediately. The exceptions are usually loose sandy or semi-liquid muds that flow into the excavation, rather than cave or slide into it.

Stabilizing. Sloping of sides for stability is a technique chiefly used for permanent open ditches, which will be discussed later in this chapter. It is seldom used for trenches for burial of pipes because of the large amount of extra digging, the space required, or the area of pavement, lawn, or other surface disturbed.

Vertical trench walls may be stabilized by bracing, draining, freezing, or chemicals. Bracing is the most common technique, and may be required by law.

Bracing Structures. Figure 5-9 (A) shows a light system of bracing or shoring used where danger of caving is slight. Planks are placed vertically in the trench at five to fifteen foot intervals, and pressed against the dirt by means of push-type turnbuckles, called sheeting jacks. Bracing timbers are inserted and the jacks removed. The planks are usually two or three inches thick, the cross braces six by six or larger. Wide ditches require heavier cross braces than narrow ones.

A heavier type of shoring is shown in (B). The sides of the ditch are lined solidly

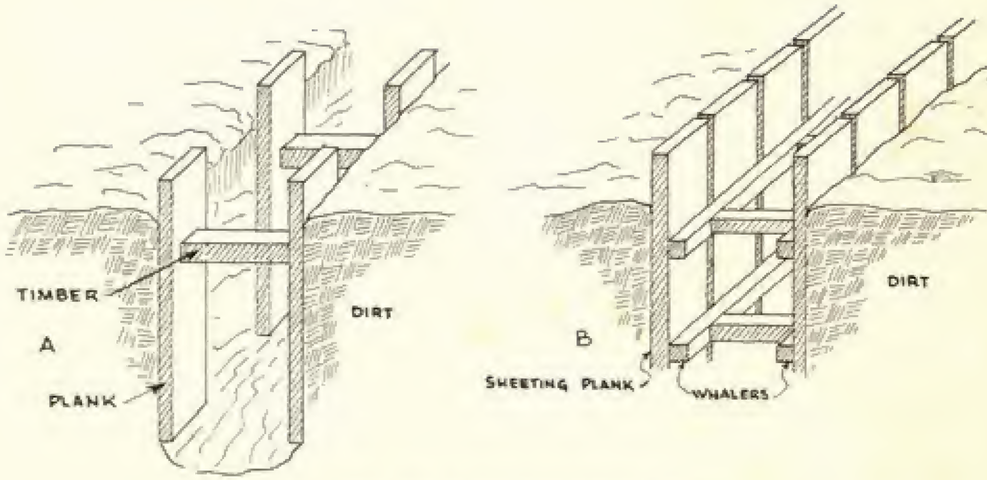


Fig. 5-9. Bracing trench sides

with vertical planks, called sheeting planks, held from falling inward by horizontal beams, known as whalers, which are braced to each other across the ditch by timbers. These timbers are sprung into place by forcing the whalers apart by sheeting jacks.

The weight and spacing of the planks and timbers will be determined by the depth and width of the ditch, and the instability of the soil. It is possible for a usually safe soil to be dangerously soft locally, due to disturbance of underground drainage, leakage of water mains, or other causes, so an ample margin of safety should be allowed.

Figure 5-10 shows photographs of shored trenches. Note the nailed strips that hold the timbers up against the whalers.

Delayed Bracing. The method of placing the braces is determined by the promptness with which the banks are expected to collapse. If they are so stable that the necessity of bracing is questionable, the ditch may be dug by shovel or ditcher, closely followed by the carpenters who build the bracing in place as a completed structure, as close against the sides as is practicable.

Immediate Bracing. If the banks are not trustworthy, or the contract calls for immediate bracing, the ditch is made enough wider than the bucket so that it can work between the whalers. The ditch is dug to a depth of about two feet, full width, and the top pair of whalers placed, and cross braces set with such spaces that the bucket can get down between them. Planks are set vertically touching each other outside the whalers.

The shovel, preferably a clamshell, now digs a foot or two below the whaler. Men with handtools dig the dirt out from under the vertical planks, allowing them to settle, and also remove dirt under the crossbeams which the buckets cannot reach. This dirt is piled in the middle of the ditch and is taken out by the bucket when the laborers are out of range. The shovel then digs deeper and is followed by handtool work. At a depth of two to five feet below the top whaler, another pair of whalers is set inside the planks and braced across the ditch. Alternate excavation by shovel and handtools, undermining and dropping of side planks outside the whalers, and installation of additional beams is continued until bottom grade is reached. Ordinarily, the whalers and crossbeams are either heavier

Fig. 5-10. Braced trench

or more closely spaced with increasing depth as the potential pressure increases.

If the ditch is deeper than the length of available planks, those started at the surface should be of variable length. As each one drops below the top whaler, another plank is placed on top of it to follow it down. Mixed lengths make this possible without weakening the structure by having a row of these joints occur together.

The whaler beams are also of different lengths so that both members of a pair do not end together. The joint between any two can therefore be braced against a solid beam on the other side.

Two or three inch sheeting, and six by six whalers and crossbeams, spaced five to eight feet apart, are strong enough for moderate depths in most soils. If more protection is needed, heavier wood may be used, additional planks can be driven outside the sheeting, or inserted inside by a complicated process of removing and replacing whalers. Steel sheet piling is much stronger than wood.

Movable Bracing. When the work which is to be done in the ditch can be completed in short sections so that the ditch can be backfilled a few yards behind a hoe shovel, a portable bracing structure can be used.

It may be made up of steel or wood, and should be equipped with a tow bar or chain at the front bottom, which can be gripped by the bucket teeth. It is lowered into the first section dug, and the pipe laying or other work done inside it while another section is dug. The shovel drags it along in the ditch whenever sufficient digging or pipe laying has been completed to justify moving it.

Such a device can result in tremendous savings. However, it cannot be used on many jobs because of the necessity of checking the work, or having it inspected.

Also, if the sides should close in on it, it might be very difficult to free up for moving.

Backfilling should be done as soon as possible, as allowing the sides to cave may damage the pipe, or shift it out of line.

Flowing Banks. If the sides are so unstable that they cave or flow immediately upon being cut, the sheeting planks must be driven down by air hammers or pile drivers, and the dirt dug from between them afterward. Penetration and control of direction are usually best if the planks are driven only a short distance below the digging. However, mud may flow so readily that the sheeting must be down several feet below excavation level to prevent it from swelling on the bottom. All graduations between this condition and stable banks may be encountered in a short distance.

Washout Failures. Only wet ground or loose sand exerts very heavy thrusts against the shoring. Water draining down the sides of a braced trench may erode them, so the sheeting moves outward, thus loosening the cross beams or jacks and allowing them to fall, after which the sheeting can be pushed in by any movement of the banks.

Well Points. Where shoring is difficult and expensive, it may be economical to dry up the area with well point pumping, or to seal and stabilize the banks with injections of chemicals. Well points are discussed later in this chapter.

Chemical Stabilization. Chemical treatments are of two types. The most common is injection of a cement grout or other liquid that will congeal in the soil spaces through which water is moving. This technique is briefly discussed in Chapter 16 concerning sealing small leaks in ponds.

Other chemicals may react with the soil itself to produce a relatively hard, impermeable substance. These are usually applied by specialists after careful soil analysis.

Freezing. Mud may be frozen by sinking refrigeration pipes in it. This is an expensive operation, justified only when the mud is too fine grained to be dried by well points, or when some special condition makes their use impractical.

PERMANENT DITCHES

When a ditch is to be left open permanently, its sides usually must be protected by masonry or rot-resistant sheet piling, or sloped back far enough so that they will not slump, cave, or wash into the bottom. If a large volume of water may flow through the trench at any time, the bottom should also be protected against erosion, unless the gradient is so flat, or the water so burdened with silt, that cutting will not occur.

Ditches with low gradients, or which carry dirty water, must be cleaned out periodically by a dragline shovel or other excavator. Masonry, riprap, and particularly vertical stone walls interfere with machine digging and are liable to be damaged. This should be borne in mind in designing any artificial protection.

Sloped Banks. The most satisfactory bank protection for a country ditch is a stable slope and a good cover of vegetation. This can be reinforced on the outside of bends and other places subject to strong current action, by placing large boulders, walls, riprap, or light piling holding wire or brush mats.

Stable slopes vary in steepness with the character of the soil. Loess may stand indefinitely in vertical cliffs, while certain types of clay may slump if the slope is one on six. Generally, it may be said that slopes of one or two and a half or less are advisable if the soil contains much clay or silt; if there is movement of ground water through it toward the ditch; if there is considerable drainage of surface water running down its face, or if it is in layers that dip toward the ditch.

Vegetation. If trees are to be planted or allowed to grow, the slope can be steeper than if it is to be kept in grass. Trees have greater holding power, and maintenance of grass may require the use of mowing machines, whose ability to work on side slopes may determine the grade. However, trees will interfere with access for cleaning.

If the trench is partly or wholly in barren soil, topsoil may have to be spread on the banks to encourage vegetation, although some plants can generally be found that will grow well on the subsoil if encouraged with lime or fertilizer.

Banks of permanently wet ditches may be strengthened by laying willow poles or logs up and down the bank, two to four feet apart. They should be settled well into the soil for their full length, with the lower end in water or bottom mud, and staked or wired in place.

These poles should grow tops and a continuous root mattress.

Bottom scour may be largely prevented by keeping a gentle gradient. If any portion of the trench is too steep, a series of check dams may be built.

This localizes the fall of the water at the erosion-resistant aprons of the dams. Good results can sometimes be obtained with plank dams, or even heavily anchored brush mats.

Spoil Arrangements. The spoil piles from a ditch are apt to interfere with local surface drainage. If the land is flat, spoil may be piled on both sides, but frequent breaks should be made in the windrows so that water will not pond behind them. If the ditch cuts across a slope, these breaks need be made in the upper pile only. Until the ditch slope is protected by vegetation; gullies may form at these spots unless the area is protected by pipe, flumes or stone.

The "W" ditch, Figure 5-11, is a double ditch, separated by sufficient space to provide disposal area for the spoil. This eliminates any blocking of drainage on either side, and allows maintenance of field grade to the ditch edge.

If the depth of the ditch is determined by the flow capacity required, two can be more shallow than one. This construction is only slightly more expensive than the single drainageway, although it usually takes more land out of production.

If depth is determined by a flow gradient, a W-ditch will about double the amount of excavation required. If the depth is considerable, the additional spoil is likely to damage an excessive area.

Whenever possible, the spoil piles from permanent ditches should be rounded off so as to permit easy access to the ditch and to make them less prominent in the landscape. This should be done before they are overgrown by trees.

Fig. 5-11. "W" ditch

PIPES AND CONDUIT TRENCHES

Most trenches are dug to bury pipes or conduits. Conduits, and pipes for gas and water supply, run at more or less fixed depth below the surface. Sewers, storm drains, and other gravity flow pipes must maintain a minimum gradient from source to outlet or booster pump, and will have a variable depth below an irregular surface.

Fixed Depth. In cold-winter areas, water pipes are laid below the frost line in the ground. Conduit and wires are laid only deep enough to protect them against accident. In either case, depth may be increased under sharp ridges to provide smooth vertical curves.

Depth is usually specified in a contract, or chosen according to local custom. Items to consider in arriving at it include, in street work, possibility of repaving with a thicker pavement with very high loads on the subgrade during construction, or of lowering the street surface. In fields, the most important menace is the moldboard plow, which penetrates eight or ten inches. There is a chance that a subsoil plow, with a penetration of eighteen inches to two feet, might be used, and in addition land even on gentle slopes gradually washes away, and the surface may be lowered several inches during the life of the conduit. Depths of two to four feet are usual, and are figured from the surface of the ground regardless of slope.

Since the bottom of such a ditch follows the surface at a fixed distance, depth measurements during digging are easily made. A rule or marked pole is set vertically at the side, or a board is placed across the ditch and its distance from the bottom measured.

If the depth requirement is only approximate, a mark on the stick of a backhoe, the cable of a clamshell, or the depth gauge of the ditcher may be sufficient guide.

Gravity Systems. Digging accurately for a sewer or other gravity system requires close supervision. A number of methods are used to keep on grade, of which a few examples will be given.

The grade can be checked from inside the ditch with a transit level. The beginning of the ditch is dug to proper depth, which may be measured from the surface or dictated by a connection with a pipe or manhole. This starting point is taken as a bench mark (see Chapter 2), and usually as zero station. Other stations are measured off as digging progresses, and their elevation taken with the instrument. Each successive station should be higher or lower than the starting point, according to the gradient. In the example in Figure 5-12, the drop is one foot in sixty feet, and the readings are taken at ten foot intervals.

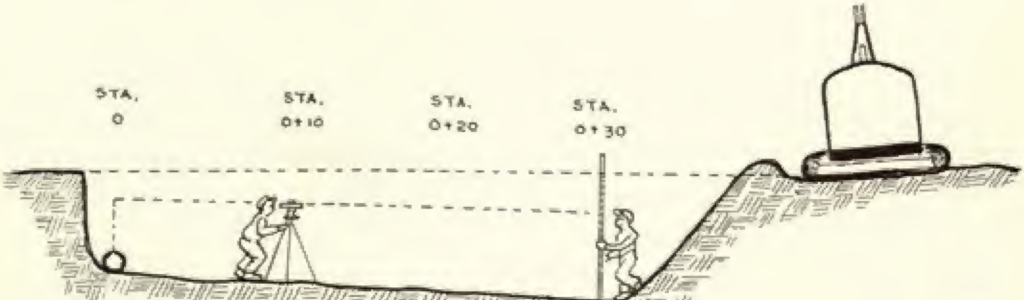


Fig. 5-12. Measuring gradient inside trench

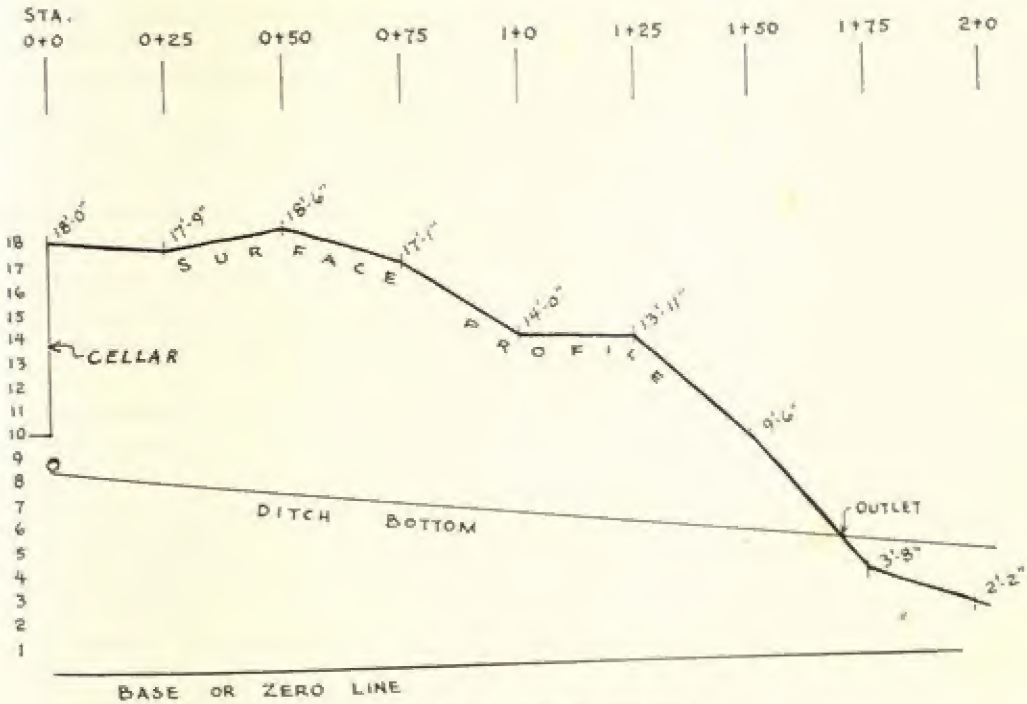


Fig. 5-13. Calculating gradient

If the ditch is correct, each rod reading should be two inches higher (the lower the ground, the higher the reading) than the previous one. If distances are measured with a tape, it must be horizontal to get an exact result.

Readings are taken as close to the digging machine as possible.

If the ditch makes an angular turn, the instrument is set at the angle point. If the ditch curves, inside work is not practical.

This way of setting gradient is liable to suffer from cumulative errors in either measurement or rod reading, unless it can be checked against surface features occasionally.

Measuring from Surface. If depth is to be measured from the surface, a profile of the ground on the center line, or on a side or offset line of the ditch, is taken. This consists in marking it off with station stakes at regular intervals, and taking the elevation of each. If the elevation of the ditch bottom is given in the plans, the amount of cut at any station may be found by subtracting the bottom elevation from the surface elevation. Stick or rule measurements may be made at these points during the digging, and any intermediate levels that are needed can be found by a hand, transit, or string level used inside the ditch.

Plotting Profiles. If there are no plans, or if they merely specify a gradient, the surface profile should be drawn to scale on a sheet or strip of cross section paper.

In Figure 5-13, a cellar has been dug and it is desired to lay a pipe on a slope of one foot in fifty feet, to take water from a tile drain laid around the outside of the footings. An instrument is set up and the elevation of the cellar floor taken. This is arbitrarily assigned a value of ten, and is used as a base or bench mark for the rest of the work. Another bench mark on a tree or some surface spot not affected by building work should also be taken for future reference.

A profile is then taken along a down

slope, until an elevation is found which is substantially below the cellar floor.

The figures obtained are plotted on a piece of cross section paper, which might be ten squares to the inch. A horizontal scale of one inch to twenty-five feet and a vertical scale of one inch to five feet are selected. The width of each printed square will then indicate two and a half feet, but its height only six inches.

The cellar is sketched in and a base or zero line drawn twenty squares below its floor. The stations, starting at zero at the cellar wall, are marked off on the vertical lines.

Each of the station elevations may now be marked on the diagram by measuring up from the base line one square for each six inches. These dots are connected by a line which is a picture of the surface slope, with its steepness exaggerated.

The ditch may now be drawn in. A distance of a foot and a half below the corner of the cellar is scaled off and marked at zero station. At station two plus zero, a distance of eight squares representing four feet below the level at zero station is marked, and a straight line drawn between them.

Measurements on this sketch will now give the length of pipe needed, the distance on the ground to the outlet, the elevation of any point on the ditch bottom, and the depth of the ditch anywhere.

A larger scale in which each square would represent a smaller distance will give more accurate readings.

Finish Levels. When the digging of a ditch section is finished, boards may be placed on edge across the ditch at 10 to 25 foot intervals, and staked or otherwise firmly fastened in undisturbed soil, in positions such that a tight string may be run over the ditch and adjusted by instrument readings to be parallel with the final grade of the bottom. Extra strips of wood may be nailed on, or notches cut into original boards, if they are too low or too high. Finishing of the bottom, and placement of pipe, is governed by measurements down from this string.

Street Pavements. Hard pavements are generally broken up in advance of the digging. If the street is to be repaved after the trench work is completed, the whole pavement may be smashed and removed by a large dipper stick or dozer shovel; or torn up with a heavy ripper and dug away by smaller machines.

If the pavement is to be preserved so far as possible, it should be broken along the line of the ditch by pavement breakers. Wide edge chisels are used for blacktop, narrow or pointed tools for concrete, and weight-dropping machines for either. The two edges are wholly or partially cut. The strip to be removed may be broken up by the tools or by the excavator.

Reinforcement in concrete greatly increases the cost of this work. Thin bars may be cut by the chisels, heavier ones may require a cutting torch or heavy bolt cutters. The work involved in exposing the reinforcement may be greater than that in cutting it. The broken pieces of pavement may be removed by hand, or may be left for the ditching shovel to take out with the dirt.

BACKFILLING

General Methods. Trenches dug for laying of pipes or conduits must be backfilled when the installation is complete. The dirt taken out is pushed or pulled back in. This job can be handled by most earth moving machines, but the bulldozer is the standard tool for the purpose.

If the backfill need not be compacted from the bottom up, it may be pushed into the trench in the ways shown in Figure 5-14. The bulldozer operates at right angles to the trench, taking as large a slice of the pile as it can handle comfortably. Dirt which drifts across the blade is left in windrows that are pushed in a separate

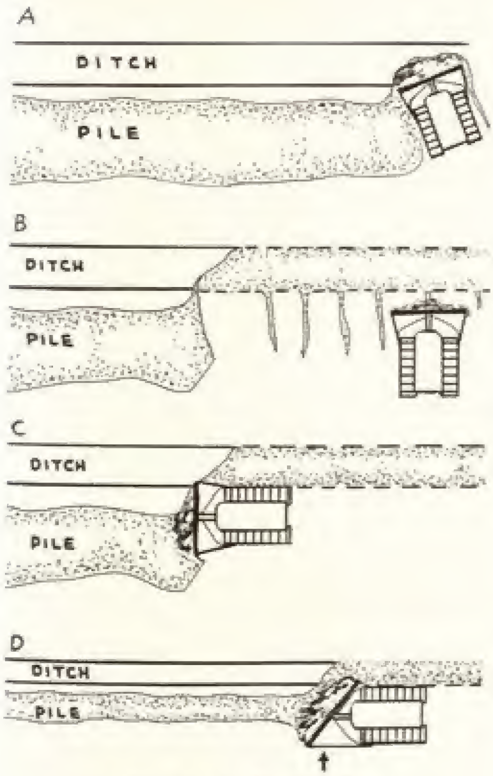


Fig. 5-14. Backfilling

series of passes, as in (B). Any remaining soil is pushed parallel with the ditch into the main pile as in (C), or, when the end is reached, distributed along the ditch.

There will usually be too much soil because of increase in volume of disturbed soil, and space occupied by the pipe laid. The excess may be mounded up over the trench and partly compacted by use of a roller, or driving the dozer or a truck along it. Full natural settlement may take as much as a year, and is liable to leave low and high spots to be graded in.

If the trench is small, it may be refilled by running an angle dozer or a grader through the pile, with the blade set to side cast it into the ditch as in (D).

Heavy backfill may be done by a dipper shovel walking through the length of the pile, digging it and dumping in the ditch. A backhoe or a dragline can work from across the ditch, pulling the soil into it. A dragline's efficiency will be greatly increased by fastening a heavy plank or other block across the mouth of the bucket so that it will not fill. Shovels are often used to move the bulk of the backfill with a bulldozer doing the final cleanup.

When pavement along the sides of the ditch is to be preserved, the best tool is a very light dozer, or a medium one with flat or rubber shoes, or a rubber-tired dozer shovel.

Special dragline type backfillers are often used on cross-country trenches.

Compacted Backfill. If a pavement is to be laid over the refilled trench immediately, the backfill must be carefully compacted from the bottom up. This may be done by dozing or hand shoveling fill slowly, while men in the trench compact it with hand or pneumatic tampers. A mechanical tamper may work from the side or straddle. The top layer may be compacted by use of a trench roller with a large wheel that will fit inside the ditch, or by running any heavy machine back and forth along it.

Open textured soils may be effectively compacted by puddling. Enough water is added to the fill to make it into mud, which, upon drying, will shrink considerably. Heavy soils take a long time to dry so are not as readily handled this way.

Machinery should not be run along wet trench fills as it is almost sure to get stuck in them.

Imported Backfill. Drainage trenches are often refilled with porous material differing from that dug out. The spoil of the original digging is trucked away or used in grading, and the gravel trucked in for refilling. This may be dumped in piles in and alongside the ditch, and pushed into it by a dozer or grader or hand shoveled. If considerable work of this type is to be done, a backfilling machine may be profitably used. This carries a hopper that is moved parallel with the ditch by rubber tired driving wheels.

Trucks dump into the hopper from which a belt carries the soil to the ditch and dumps it. The backfiller can push the truck which is dumping into it, so that the truck driver can concentrate his attention on lifting the body at proper speed.

DEWATERING

DRAINAGE

Both the surface and the subsurface water may be removed by a seasonal drop in ground water level; drainage through ditches, pipes, or siphons; by pumping; by walling off or diverting the source of water, and very often by combinations of two or more of these methods.

The purpose of dewatering may be to promote growth of crops; to dry out swamps or other objectionable wet areas; to stabilize slopes, foundations, and road subgrades, or to facilitate excavation for any purpose.

All of these objects except the last are accomplished chiefly by drainage—that is causing the unwanted water to flow away through artificial and natural channels or conduits. Pumps may be used to remove water from a sump or low point of a drainage system.

Gradients. The slope or gradient of a drain will depend on the work it has to do. In tidal marshes and other practically flat swamps, ditches with zero gradient may serve to lower the water level substantially. In general, water will flow through a flat ditch, but it is easily choked by sediment, growth of weeds, and dirt falling from banks, as the water flowing through it will have little or no ability to clean it. Too steep a ditch gradient may cause erosion of the bottom, undermining of banks through stream action, and damage from depositing of mud below the discharge point.

The slope must be adjusted first to the necessities of the situation, and second to the relation between the amount of water to be carried and the nature of the soil. A bottom gradient between one foot drop to 1000 feet and of two feet to 100 feet is desirable under most conditions encountered.

Drainage pipes should not be flat as costs in cleaning out sediment and debris will be very high. Low gradients can be used when the water is clean, the pipe is short and large enough to allow men to work in it conveniently, or there is a sharp fall at the outlet so that water will flow rapidly. Generally, the minimum gradient should be six inches to 1000 feet, and the maximum two feet in 100 feet for land tile, and ten feet in 100 for tight joint pipe.

Special erosion resistant pipe may be laid on steeper slopes.

Surface Water. Surface drainage may consist of disposal of water from rain or melting snow, or lowering the water level in ponds, ditches, or swamps. It may use open channels, conduits, or both. The water is usually led to a natural stream or body of water.

Such drainage may be accomplished by deepening, enlarging, or straightening and protecting existing streambeds, by digging artificial channels, or installing underground pipes or tunnels.

There is no definite separation between surface and subsurface drainage as they operate on different parts of the same water mass.

Tunneling. If it is not practical to ditch to install a drain or diversion pipe, boring or tunneling may be used. Diamond drills will put small holes into rock hillsides at any angle desired, for long distances. Augers will drill soft rock up to a hundred feet or more. Where such machines are not available, or where a larger drain is needed, tunneling may be done with explosives and hand digging.

Siphons. If a drainage line is to be used only occasionally, the expense of ditching

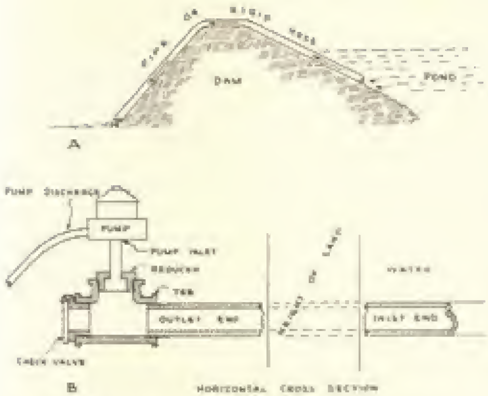


Fig. 5-15. Siphon and priming pump

or tunneling may be avoided by use of a siphon. This is an airtight pipe or stiff walled hose, one end of which lies in the water to be drained, and the other at a lower level, with the intermediate part passing over the dam or height of land which interferes with natural drainage, as in Figure 5-15 (A). When the pipe is filled with water, that which is between the high point and the lower or discharge end moves down the pipe by gravity, while atmospheric pressure, acting through the pond water, pushes the shorter and lighter column of water after it. This water is in turn renewed from the pond so that movement continues until the water level drops sufficiently to outbalance the suction, or to allow air to enter the pipe; air enters through leaks or through the discharge end, or water rises around the outlet to the same level as the intake.

The rate of flow will depend chiefly on the drop between the top of the water being drained, and the point where the water loses contact with the outlet end of the siphon. As a pond is drained and its level drops, the flow will become slower.

Siphons in which water moves slowly are likely to be stopped by air entering the top of the outlet. This may be prevented by putting the outlet in a box or small pool so that the opening will be under water. A slow current may also allow an air lock to form from the accumulation of air or other gases escaping from the water in the pipe, or leaks from the outside.

Very small siphons may be started by mouth suction and a medium size by inverting it so that the ends are higher than the middle, filling it with water and holding the ends closed while placing it in position. Or a tee connection in the top may be used to pour water in, keeping the ends plugged until the pipe is full and the tee tightly plugged.

The most satisfactory way to start a large siphon is with a suction pump. A way to connect it is shown in (B). A tee is placed on the outlet end, with the side opening reduced to fit the inlet hose of a small diaphragm or centrifugal pump. Means are provided to prevent air from entering through the lower opening of the tee, by means of a check valve, a screw plug, or a piece of plywood with mud on it. With this stop in place, the pump is started and the air sucked out of the siphon so that water from the pond is drawn through it into the pump. The stop on the main pipe then opens or is removed and the pump is shut off.

Channels. Channels may consist of natural watercouses; watercourses which have been enlarged, straightened, or paved; or artificial ditches.

A stream bed may be dredged to lower its level, to increase its depth or capacity, to keep it from changing its course, or to change its course.

Level may be lowered to drain surface water from a swamp or pond, or to provide better underdrainage for land in its vicinity.

Depth is usually increased to assist navigation, or to provide for more rapid runoff of flood water. Widening and straightening increase capacity, often at the expense of depth.

Streams normally wander in their courses, cutting away banks in some places

Fig. 5-16. Pipe details

and building them in others. When valuable property or structures are threatened by these changes, the channel may be artificially shaped to direct the force of the water away from them. This may involve turning the water back to its original direction, or forcing it to flow in a new one.

Dredging of small streams is generally done from the banks by draglines or clamshells, and of large ones by floating dredges. The material dug may be piled on the banks, or removed by trucks or barges.

When the spoil is used to build banks to control stream direction, it must be protected by paving, masonry, rock, logs, wired brush, sod, or other material. The best emergency protection for a bank that is being washed away is drilled boulders fastened together in groups of three with steel cable.

River dredging may be planned to direct the river current so that it will do most of the excavating in the new channel.

Drainage channels are often paved to protect them from erosion or slumping, to prevent changing of course, and to increase capacity by reducing friction.

Irrigation canal pavements may be used for any of these purposes and to prevent

INSIDE PIPE DIA.	CONCRETE SEWER PIPE						CONCRETE CULVERT PIPE						CORRUGATED METAL PIPE				
	PLAIN A.S.T.M. SPEC. C-14-41.			REINFORCED A.S.T.M. SPEC. C-75-41.			REINFD. STAND. STRENGTH A.S.T.M. SPEC. C-76-41.			REINFD. EXTRA STRENGTH A.S.T.M. SPEC. C-76-41.			16 GAUGE	14 GAUGE	12 GAUGE	10 GAUGE	8 GAUGE
(INCHES)	SHELL THICKNESS (INCHES)	WT. PER LIN. FT. (lbs.)	ULT. STRENGTH 3 EDGE BEARING LBS. PER LIN. FT.	SHELL THICKNESS (INCHES)	WT. PER LIN. FT. (lbs)	ULT. STRENGTH 3 EDGE BEARING LBS. PER LIN. FT.	SHELL THICKNESS * (INCHES)	WT. PER LIN. FT. (lbs)	ULT. STRENGTH 3 EDGE BEARING LBS. PER LIN. FT.	SHELL THICKNESS † (INCHES)	WT. PER LIN. FT. (lbs)	ULT. STRENGTH 3 EDGE BEARING LBS. PER LIN. FT.	WT. PER LIN. FT. (lbs.)	WT. PER LIN. FT. (lbs.)	WT. PER LIN. FT. (lbs)	WT. PER LIN. FT. (lbs)	WT. PER LIN. FT. (lbs)
4	9/16		1000														
6	5/8	25	1100														
8	3/4	35	1300										7.6	9.3			
10	7/8	48	1400										9.3	11.4			
12	1	60	1500	2 §	90	1800	2	90	2250				10.8	13.3	18.5		
15	1 1/4	90	1750	2 1/4 §	125	2000	2 1/4	125	2625				13.3	16.4	22.7		
18	1 1/2	120	2000	2 1/2 §	160	2200	2 1/2	160	3000				15.8	19.5	27.0		
21	1 3/4	190	2200	2 3/8 §	205	2400							18.3	22.5	31.2	39.7	
24	2 7/8	225	2400	2 5/8 *	225	2400	3	260	3000	3	320	4000	21.0	26.0	35.9	45.7	
30				3 *	315	2700	3 1/2	370	3375	3 1/2	470	5000		31.7	43.9	55.9	
36				3 3/8 *	450	3000	4	520	4050	4	600	6000		37.9	52.4	66.7	81.1
42				3 3/4 *	560	3200	4 1/2	680	4725	4 1/2	750	7000		44.4	61.5	78.3	95.1
48				4 1/4 *	720	3400	5	850	5400	5	1000	8000		50.5	70.0	89.1	108.3
54				4 5/8 *	880	3700	5 1/2	1050	5850	5 1/2	1050	9000		57.8	80.1	102.0	123.9
60				5 *	1060	4000	6	1280	6000	6	1280	9000			88.2	112.3	136.4
66				5 3/8 *	1250	4250	6 1/2	1480	6300	6 1/2	1480	9500			96.6	123.1	149.5
72				5 3/4 *	1560	4500	7	1835	6600	7	1835	9900			105.1	133.9	162.6
84				8 §	2000		8	2300		8	2300					156.6	190.3

* Conc. 3500 p.s.i. § Conc. 3000 p.s.i. † Conc. 4500 p.s.i.
Ultimate strength given for reinforced concrete pipe is A.S.T.M. "first crack" strength.
Standard laying length – 4 ft.
Weights per lin. ft. furnished by Universal Concrete Pipe Co.

Furnished in any length in multiples of 2 ft.
Data furnished for Armco Pipe by Shell Co. Elmira, N.Y.

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Fig. 5-17. Pipe classes and properties

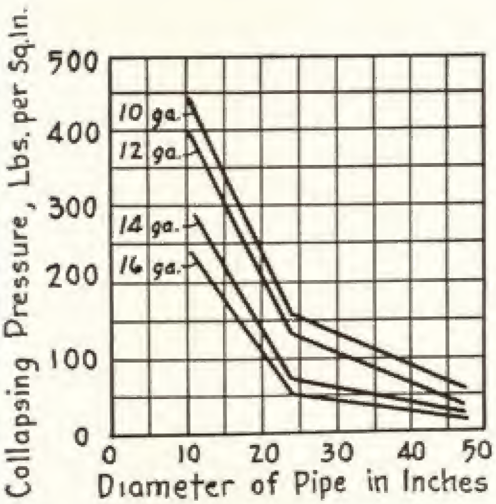


Fig. 5-18. Ultimate collapsing strength of corrugated pipe from exterior hydrostatic pressure

water from leaking out of the canal into surrounding soil.

Check Dams. When the slope of a channel or gutter is so steep as to make erosion likely, it can be divided into a series of easy gradients, and separated by check dams over which the water falls steeply.

It is important that each dam have a center spillway large enough to prevent water from overtopping the edges and eroding the earth alongside. An apron is also necessary to prevent undermining.

Where elaborate structures are not practical, crude ones made out of brush and logs or loose stones may serve the purpose.

PIPE

Drain and culvert pipe is made in sizes with inside diameters ranging from three inches to fifteen feet. Materials include concrete, tile (vitrified clay), transite (cement-asbestos), and corrugated iron or steel. Figure 5-16 indicates the names of various parts of a pipe cross section.

The tables in Figure 5-17 show some properties of concrete and corrugated pipe. Strength of the metal pipe is not shown here because this is in part a function of the support it has on the sides.

Ordinary vitrified clay pipe is comparable in strength to plain concrete sewer pipe, and extra strength clay to reinforced concrete culvert pipe. Transite is available in a number of classes that vary from the strength of plain concrete to twice that of reinforced concrete. Both the tile and the transite are brittle and fragile to handle.

Figure 5-18 shows the approximate strength of corrugated pipe.

Concrete. Concrete pipe may be plain or reinforced, the joints may be butt, bell, slip joint, or gasketed. Size range is from four inches in inside diameter and up. Lengths are two, three, four, and eight feet.

Butt (open) joints are used for land tile.

Bell joints are resistant to chipping, will hold the pipe against slipping downhill, and, if the joints are open, will reduce flow or seepage of water along the outside of the pipe, but are difficult to lay.

Slip joints are easier to handle and to lay because of the uniform outside diameter.

Pipes over 12 inches inside diameter are usually reinforced, and this construction is required on most jobs because of its additional strength.

Concrete may be attacked by water carrying certain alkali salts or other chemicals. It is subject to erosion from fast flowing water carrying abrasive material, and may scale or disintegrate slowly from weathering. Structural difficulties may arise from the comparative weakness of its joints. However, under a wide range of conditions, it is long lived enough to be considered a permanent installation.

Tile. Tile may be porous or glazed, and is chiefly made in small and medium diameters, and in one to four foot lengths. The porous type usually has butt joints and is called land tile. Standard glazed or vitrified tile has bell joints and is called sewer tile.

Tile is lighter than concrete and has ex-

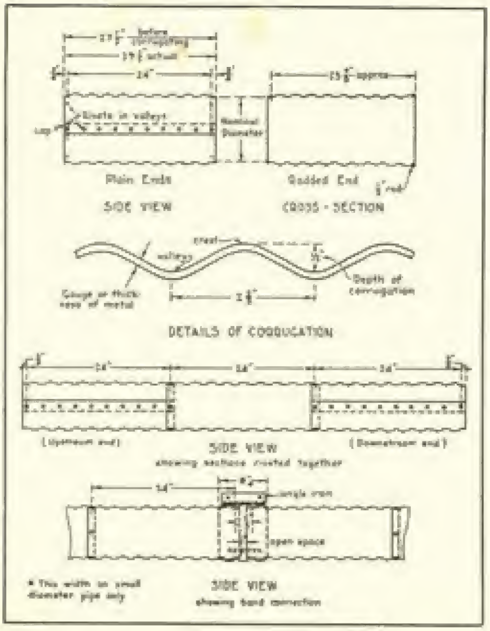


Fig. 5-19. Corrugated pipe detail

cellent bearing strength and resistance to weathering and corrosive chemicals. Its glazing resists erosion. It is fragile, and must be handled with care. In small sizes it is cheap and easy to lay except on unstable ground.

Transite. Transite, or cement asbestos pipe, is a light composition with very high pressure and crushing resistance. Diameters range from four inches to 36 inches. Sections are 13 feet long with gasketed collar joints. They must be handled carefully to avoid breakage.

This material is widely used for water and sewer lines, but is too expensive for ordinary drains.

Corrugated Metal. Corrugated pipe is made in standard, helical, and heavy duty constructions. Cross section may be round, elliptical, flattened, or arched.

Standard pipe, illustrated in Figure 5-19, is made up of galvanized plates of rust-resistant (but not rustproof) iron or steel, 16 gauge to 8 gauge, which are deformed with parallel corrugations or ripples. These are usually 2⅔ inches from crest to crest, and ½ inch deep. They increase the strength of 16 gauge about eleven times, and of 8 gauge about 3½ times.

The corrugated plates are rolled into cylinders slightly more than two feet long, which are lapped and riveted together. Additional cylinders are lapped over the ends and riveted to obtain the desired length.

Several gauges are available for most pipe sizes to permit varying strength to suit requirements.

Inside diameters of standard riveted pipe range from six inches to eight feet. Lengths may be made up in any multiple of two feet, but transportation problems usually limit single pieces to 20 to 24 feet.

One end of an end section of light gauge pipe may be lapped around a reinforcing ring.

Pieces can be made up with beveled or skewed ends.

Pipe sections are fastened together on the job by band collars. These may be one-piece or two-piece. One-piece bands are usually fastened by compression bolts only. Two-piece may be riveted or bolted to the sections. Because of allowance for overlap, each pipe section is 1½ inches longer than its nominal length. Each joint adds the width of one corrugation to overall length.

Features of arched pipe are lower clearance, greater bottom capacity, and less tendency to settle in soft ground.

Under normal conditions, corrugated pipe gives long service, but its life may be shortened by chemicals or electro-chemical action, and by erosion of the bottom.

Corrosion can be checked by an asphalt coating, or for more severe conditions, by asbestos bonding. A mat of asbestos fibers is pressed into the molten zinc coating as a final step in the galvanizing process. The exposed fibers are then saturated with a bituminous protecting coat.

Erosion is reduced or eliminated by

a paved invert. This is a wear-resisting asphalt pavement on the bottom which fills the valleys and covers the crests of the corrugations ⅛th inch deep. It can be applied to either galvanized or coated pipes.

Corrugated pipe is very much lighter than concrete or tile; it is not as readily damaged by carelessness or abuse; it is easily placed, connected, extended, or removed for salvage, and resists movements of fill which would pull short jointed pipes apart. Its internal flow resistance is higher than in other types. Its corrugations tend to keep it from moving in the fill, and discourage seepage or overflow following the outside. It will bridge low or weak spots in its supports.

For subdrainage it can be drilled with $\frac{5}{16}$th or ⅜th inch holes through the haunches.

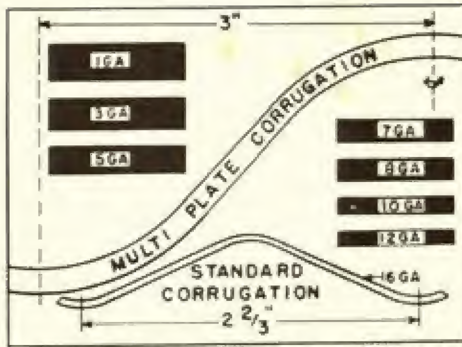
Helical pipe is made up of long, narrow corrugated sheets bonded to each other by folding the edges. It is made in small 6″ to 21″ sizes, and 18 and 16 gauge metal. It is designed primarily for subdrainage.

Armco multi-plate pipe, Figure 5-20, is made of plate from 12 gauge to 1 gauge ($\frac{9}{32}$″). Corrugations are 6 by 2 inches. Inside diameters range from 60 inches to 180 inches.

This pipe is shipped in the form of curved and drilled plates that are bolted together in location, as shown. It may also be made up into part circles or arches.

Other Types. Wood pipe is made of wood staves running the length of the section, cut to fit each other closely and bound together by wire loops. It should be full of water to keep the wood expanded and the seams watertight. It is light, easy to handle, and not particularly fragile. If its base is uneven, or if it dries out, it may leak. It is not commonly used.

Oil or grease drums may have the ends cut out and the cylinders tack welded together. Such conduit is easy to handle, but



Comparison of gage and corrugation size of standard corrugated sheets and Multi Plate plates.

Fig. 5-20. Multi Plate pipe construction

compressive strength and resistance to corrosion are poor.

It may be strengthened somewhat by stretching it vertically, in the manner to be described for corrugated pipe. Struts may

be left in permanently, but are likely to catch debris and to cause clogging. Such installations are usually temporary.

Threaded iron water pipes or well casings are sometimes used for small drains or culverts when they can be obtained second hand, or no other pipe is available. If the used pipe can be bought cheaply, it is ideal for draining small quantities of water through drives or fills during construction, if the regular drainage system is delayed. It will not pull apart under any natural stress, resists bending, can be cleaned out with a plumbers' snake, and is easily salvaged by pulling out from the end, or digging out.

BRIDGES

Where a road or other continuous embankment crosses a stream or drainageway, it is usually carried over it on a bridge or a culvert.

These structures may be distinguished from each other on a basis of width of opening. The critical width, or span, at which a bridge becomes a culvert varies from five to 20 feet in different localities.

A trestle or viaduct is a bridge that is supported on piers between its abutments, and which has a length or height in excess of that required for water flow, navigation, or traffic underneath it. It functions partly or wholly as a structural fill.

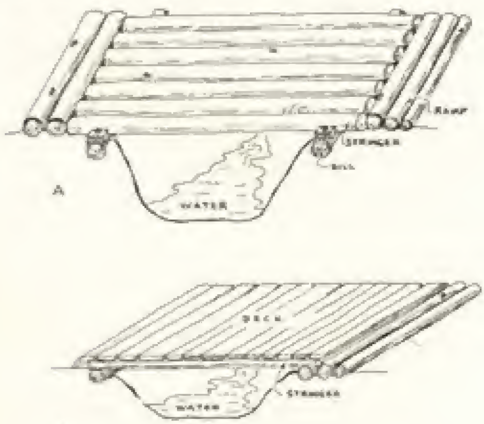


Fig. 5-21. Log bridges

Log. Figure 5-21 shows log bridges suitable for carrying a pioneer road or driveway across a small stream. Several constructions are indicated.

The most economical type is that shown in (A), in which the stringers make up the whole floor. The sill logs, which have the supporting function of abutments, prevent the stringers from settling out of line or caving the bank.

The stringers have a tendency to separate and to overturn under load. They can be held sufficiently for light traffic by drilling through them into the sills, and anchoring them with lag bolts or driftpins, and side blocking. Tires may wedge between the logs.

The construction shown in (B) is safer. The deck should be made of split logs or planks, if possible. Round logs should be bolted down to the stringers, or covered with gravel deep enough to prevent them from turning.

If the span is long, or the loads heavy, a stone filled log or timber crib may be used as a center support. Cribbing may also be used at one or both banks if they are too low or soft to give proper support.

It is advisable to anchor the bridge with heavy cables or chains secured to trees, stumps, or artificial anchors so that it will not be carried away by high water.

The strength of wood of various species, and in different conditions, varies so widely that individual judgment must be exercised in selecting the logs. If the bridge is to be used over a period of years, resistance to rot may be more important than initial strength.

Green wood is strong but lacks rigidity, and tends to give too much bounce to a long bridge. It will usually bend and splinter before breaking.

If only one side of the stream is accessible to machinery, the logs may be pulled across from that side by the use of a cable through a snatch block anchored on the

opposite bank. The block should be placed high, if possible, to prevent the end from digging into the bank.

Timber. The log bridge designs may be more conveniently built with sawn timbers when they are available and the extra expense is justified.

Timbers are also used to build a variety of small and medium size bridges and trestles that can be designed to carry very heavy loads.

Design and fabrication of timber structures is too complex a subject for discussion here. They are often comparatively inexpensive to build, but must be regarded as more or less temporary. The wood is subject to fatigue under heavy load, to decay, and to danger of destruction by fire.

Concrete. Concrete bridges consist in general of two abutments supporting a slab. The slab usually includes guardrails, and supporting ribs or stringers which may be flat or arched. The abutments are usually continued into wing walls to direct the stream through the opening and to protect the embankment against sliding or erosion.

Even small structures are quite heavy and require that the abutments rest on solid footings. The flow of the stream should not be restricted, as it might then scour out the material against the abutments and undermine them. Abutments must be strong enough to resist the horizontal thrust of the fill behind them.

Reinforcement should be used throughout the structure, and is particularly important in the slab and its ribs.

The forms for the slab must be supported on a temporary wood or steel bridge of considerable rigidity.

Bridges should be engineered for the site and conditions. Construction should not be attempted without experienced supervision.

CULVERT DESIGN

A culvert may be made of almost any structural material. Reinforced concrete or corrugated metal pipe, and poured reinforced concrete are standard for highways and railroads. Tile and plain concrete may be used for light service. Log and timber construction are usual in pioneer and military roads.

Water passages (barrels), may be round, arched, rectangular, or in special shapes. More than one may be used.

Capacity. A culvert serves to carry the water from a drainage area or watershed of a certain size. This water includes surface runoff of rain and melted snow and ice, and whatever ground water comes to the surface within the area.

The size of culvert opening should be determined by the amount of rain which is likely to fall in the watershed within a certain period, and the character and slope of the ground so far as it affects the percentage of water that will run off, and the speed of its flow.

Additional factors to consider are the opening required by normal stream flow before it rains, the extent to which the opening may be restricted by silting, the velocity of water in the culvert, the extent to which water not passed through it can pond against the embankment before overtopping it or damaging property behind it by flooding; and the probable damage from overtopping.

Runoff. Rate of runoff is determined by intensity of rainfall, the size and shape of the watershed, and the slope, plant cover, and the permeability of the soil.

Rainfall is measured in inches, and its intensity in inches per hour, although the period of measurement may be less than an hour. For example, a rainfall of three inches might fall at the rate of six inches an hour for thirty minutes. In calculating runoff, an adjusted or equivalent rate can be used which makes allowance for variations in rate and duration.

Each watershed has a period of concen-

tration, at the end of which the runoff is assumed to be at a maximum. This is the time required for water to flow from the farthest point in the shed to the culvert. If rainfall is continuous, and ground conditions are unchanging, the runoff at the culvert will increase from the beginning of the rain until it includes water from the whole area, after which it will continue at the same rate.

This period will be longer for long narrow watersheds than for square or round ones of similar area.

The assumptions involved are not strictly accurate as runoff increases as the ground becomes saturated, as water penetrating the soil emerges at lower levels, and the rate of flow is more rapid as the volume in channels becomes larger. However, there are so many variables that exact results cannot be obtained, and the average culvert is not important enough to justify an individual study of its drainage area.

The intensity of rainfall will determine the amount of water that will fall on an acre. The ground, slope, and vegetation will regulate how much of that water will flow off, and the speed of its flow. The number of acres in the watershed will determine the total amount of water delivered to the culvert. The period of concentration will determine the length of rainfall necessary to bring the area to the point of full discharge.

There are a number of formulas used in runoff calculations. These may give the volume of water to be expected, or the area in square feet of the culvert or bridge opening required. Information can also be obtained from performance of existing culverts or bridges, and observed heights of flood water.

The value of results obtained varies with the care with which field studies are made and with a number of factors that are difficult to work out. However, for the contractor who wishes a general guide to culvert size requirements the simplest method is the best.

Figure 5-22 contains two maps showing adjusted rainfall rates in inches per hour for average requirements, and for any installation where overflow or backing up is particularly undesirable. The table supplies the number of square feet of culvert openings required to drain various areas on the basis of one inch of rain per hour.

To determine the size of a culvert, the drainage area is measured or estimated. Topographic or airplane maps are particularly useful for this purpose. The number of acres, or the next higher figure, is selected in the left hand column. The figure opposite this acreage, in the vertical column whose description best fits the area in question, is taken and multiplied by the rainfall rate shown for the locality by the appropriate map.

This will give the culvert area in square feet. To obtain the diameter of the proper size round pipe, use the formula

$$\text{Diameter} = 2\sqrt{\frac{\text{area}}{\pi}}$$

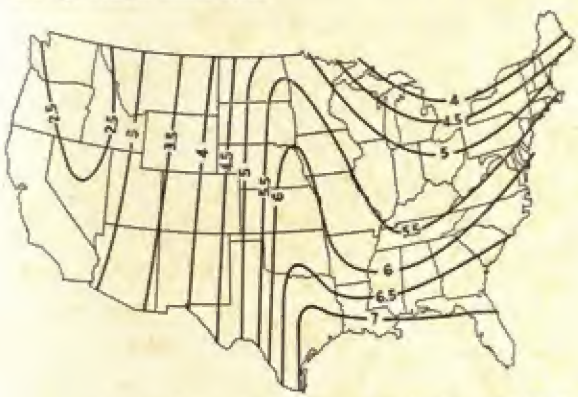
(twice the square root of the area divided by 3.14).

The indicated size should be increased if full culvert capacity may not be available, or any local conditions (such as abnormally intense rainfall, or extremely steep and non-absorbent slopes) indicate the need.

Even generously designed culverts may be inadequate for exceptional storms as it is seldom economically practical to provide for them.

Sidewalls or Headwalls. Sidewalls serve to hold embankments from falling into inlet or outlet channels; to direct water into and away from the passage or barrel to reduce turbulence and prevent undercutting of the embankment; to support the ends of the culvert, and to hold pipe sections against separating inside the fill.

Equivalent rainfall rates in inches per hour for *average* design conditions.



Equivalent rainfall rates in inches per hour for *unusual* design conditions.

Waterway Areas (Sq.Ft.) Required to Drain Different Acreages, *M*, for Equivalent Rainfall Rate of 1 In. per Hour

M acres	Flat areas not affected by accumulated snow. Length several times width	Rolling farm land. Length of watershed three or four times the width	Rough, hilly watersheds having moderate slopes	Steep, barren watersheds having abrupt slopes
2	0.08	0.14	0.28	0.42
4	0.14	0.24	0.47	0.71
6	0.19	0.32	0.64	0.96
8	0.24	0.40	0.79	1.19
10	0.28	0.47	0.94	1.41
15	0.38	0.63	1.27	1.91
20	0.48	0.79	1.58	2.36
25	0.56	0.93	1.86	2.80
30	0.64	1.07	2.14	3.21
35	0.72	1.20	2.40	3.60
40	0.80	1.33	2.65	3.98
45	0.87	1.45	2.89	4.34
50	0.94	1.57	3.14	4.70
60	1.08	1.80	3.59	5.39
70	1.21	2.02	4.03	6.05
80	1.34	2.23	4.46	6.69
90	1.46	2.43	4.87	7.31
100	1.58	2.63	5.27	7.91
150	2.14	3.57	7.14	10.7
200	2.66	4.43	8.87	13.3
250	3.14	5.24	10.5	15.7
300	3.60	6.00	12.0	18.0
350	4.05	6.74	13.5	20.2
400	4.47	7.45	14.9	22.4
450	4.89	8.14	16.3	24.4
500	5.29	8.80	17.6	26.4
600	6.06	10.1	20.2	30.3
700	6.81	11.3	22.7	34.0
800	7.52	12.5	25.1	37.6
900	8.22	13.7	27.4	41.1
1000	8.89	14.8	29.6	44.5
1200	10.2	17.0	34.0	51.0
1400	11.5	19.1	38.1	57.2
1600	12.7	21.1	42.2	63.3
1800	13.8	23.0	46.0	69.1
2000	15.0	24.9	49.8	74.8
2500	17.7	29.5	59.0	88.4
3000	20.3	33.8	67.6	101.4
3500	22.8	37.9	75.8	113.8
4000	25.2	41.9	83.9	125.8
4500	27.5	45.8	91.6	137.5
5000	29.7	49.5	99.1	148.7

10

Fig. 5-22. Culvert capacity maps and table

The wall requirement is reduced by lengthening the pipe, as Figure 5-25, top. Pipe resting on the original grade, or projecting clear of the bank as in Figure 5-23, does not usually need a wall at the outlet.

A sidewall is usually of reinforced concrete but may be of stone, wood, or metal. It may be of heavy construction and firmly founded to resist movement in any direction; or it may be light and superficial so

Fig. 5-23. Projecting culvert pipe

Fig. 5-24. Metal headwall

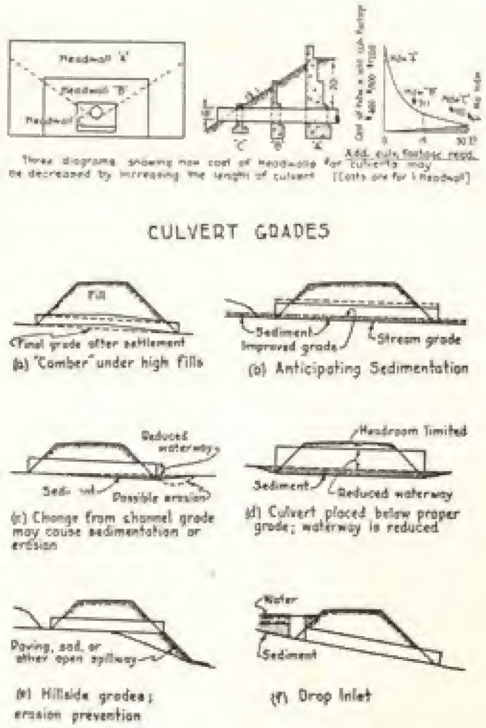


Fig. 5-25. Culvert headwalls and grades

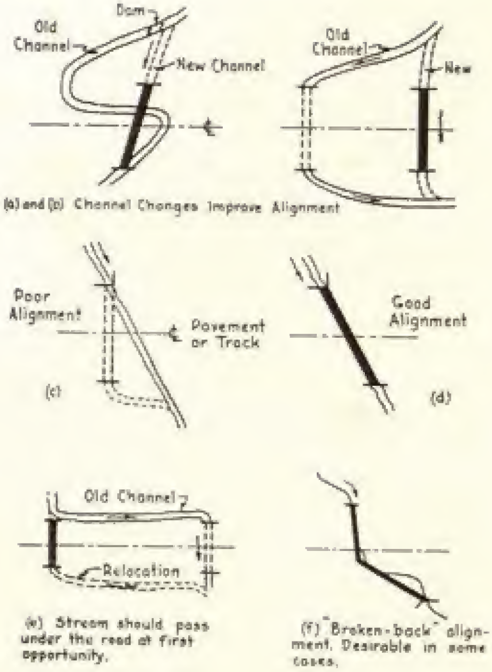


Fig. 5-26. Culvert alignment

that any settlement will affect it to the same extent as the pipe.

It is most convenient to place wall footings before laying the end pipes.

Metal headwalls, Figure 5-24, are fastened to corrugated pipe by standard couplings. They can be removed and re-used if the culvert is lengthened.

Wingwalls. Wingwalls are extensions of the headwall which serve to direct the stream, and may buttress the headwall against outward thrust. Several designs are shown in Figure 5-27.

Alignment. Culvert barrels should be straight under most circumstances.

It is usually desirable to use the original channel for the culvert passage and to have the culvert cross the road at right angles to the center line.

These two objectives are often in conflict.

The original channel may be undesirable if it is crooked, crosses at a sharp angle or skew, shows rock ridges, is made up of soft mud, or has a strong flow of water. In such cases, it may be more economical to dig a trench nearby, lay the pipe, and then divert the stream into it.

Right angle alignment may be ignored if the natural channel is diagonal, and can be easily prepared for the culvert; or when excessive trenching is required to bring the stream straight across.

Referring to Figure 5-26 (C), it will be seen that a slight change in stream alignment under the road can lead to a considerable amount of digging on the side, that the new stream channel will be out of balance, and it may require mats or revetments to protect the outside banks of the curves.

On the other hand, changes may involve comparatively little excavating and produce more satisfactory channels than the original.

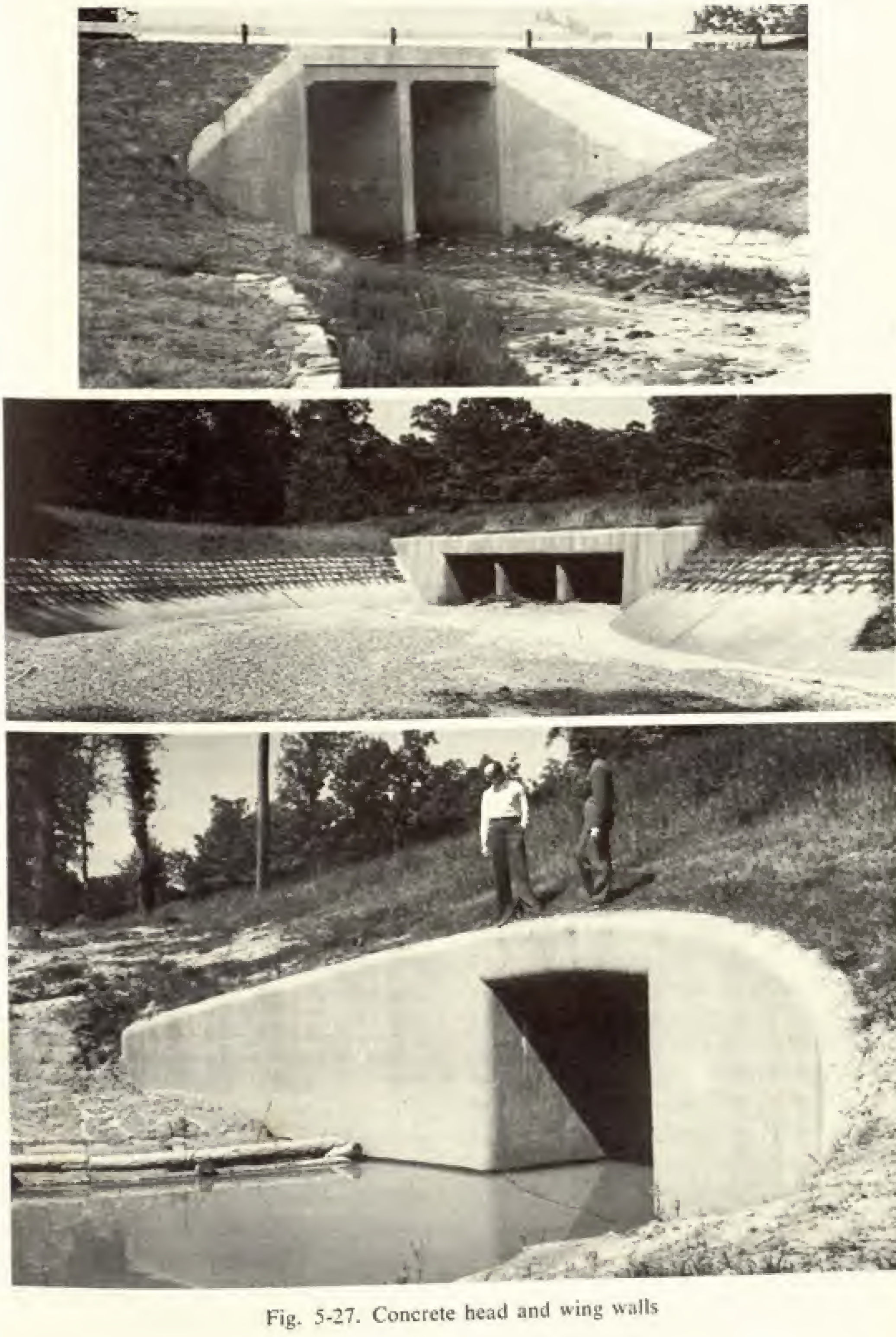


Fig. 5-27. Concrete head and wing walls

RECOMMENDED GAGES FOR STANDARD CORRUGATED PIPE UNDER EMBANKMENTS (Revised 1939)
For Highway Culverts, Municipal Drains, and Railroad Culverts Not Under Track
With Proper Backfilling and Tamping, Using Firm Material

Diam. Inches	Area Sq. Ft.	Fills Up to 15 Ft.	15 to 20 Ft. Fill	20 to 25 Ft. Fill	25 to 30 Ft. Fill	30 to 35 Ft. Fill	35 to 40 Ft. Fill	40 to 45 Ft. Fill	45 to 50 Ft. Fill	50 to 60 Ft. Fill	60 to 70 Ft. Fill	70 to 80 Ft. Fill	80 to 100 Ft. Fill
8	.35	16	16	16	16	16	16	16	16	16	16	16	14
10	.55	16	16	16	16	16	16	16	16	16	16	14	14
12	.79	16	16	16	16	16	16	16	16	16	14	14	14
15	1.23	16	16	16	16	16	16	16	16	14	14	12	12
18	1.77	16	16	16	16	16	16	14	14	14	12	12	12
21	2.41	16	16	16	16	16	14	14	14	12	12	12	10
24	3.14	14	14	14	14	14	14	14	12	12	12	10	10
30	4.91	14	14	14	14	12	12	12	10	10	10	8*	8*
36	7.07	12	12	12	12	10	10	10	8	8	8*	8*	8*
42	9.62	12	12	12	10	10	8	8	8	8	8*	8*	8*
48	12.57	12	12	12	10	10	8	8	8	8	8*	8*	8*
54	15.90	12	12	10	10	10	8	8	8*	8*	8*	8*	
60	19.64	10	10	10	8	8	8						
66	23.76	10	10	8	8								
72	28.27	10	8	8									
78	33.18	8	8	8									
84	38.49	8	8										
90	44.18	8											
96	50.27	8											

Use Multi Plate Culverts

The gages in the first column are minimum requirements for highway embankment conditions and agree with the recommendations of the A.A.S.H.O. specification.

Culverts below the heavy line should be strutted during installation.

Culverts with the mark (*) should be trenched one diameter.

The minimum height of cover should be as follows: For highways with unpaved surfaces, one-half diameter, with 12" minimum; for highways with flexible and rigid pavements, 12" minimum.

Gages heavier than those given here should be used where conditions are unusually severe.

Fig. 5-28. Recommended gauges, corrugated pipe

If good alignment between stream and culvert cannot be obtained on both sides, the upstream side should be favored. When the capacity of the culvert is heavily taxed by a storm, it is advantageous to get the water into the culvert smoothly.

Gradient. It is desirable to lay the culvert on the floor of the natural channel, on the original ground surface, or in a smoothly dug ditch. This gives firmer support than fresh fill. Inequalities in channel or ground are smoothed by cutting off ridges and tamping fill into hollows.

The passage should have at least a one half percent slope, and two to four percent is preferable. It should not be over eight or ten percent because of probable erosion of the bottom of the lining. The gradient of the waterway down from the discharge end should be as great as that above the inlet, for a long enough distance so that it will not silt up.

If the culvert is on fill or a foundation which is expected to settle, it may be laid in a vertical curve, known as camber, or to include a vertical angle. In each case, a slight gradient is used at the inlet end and a steeper one toward the outlet. Center settlement will tend to straighten out the passage.

Disjointing. If a fill settles unevenly, or part of it moves laterally, any culvert which is in it will be put under tension. Such forces are not often sufficient to break pipe but they are apt to pull apart the joints.

Metal pipe is very resistant to such disruptive forces and can be further strengthened by special joint fastenings. Short-section rigid pipe may be braced at each end by a heavy headwall, founded on underlying stable material, or may be cabled together.

Depth. Fills over a culvert, to a depth of four to seven feet, serve to protect it by spreading out the weight of vehicles on the surface. Deeper fills have diminishing protective effect and impose the load of their own weight, which at great depths may be sufficient to crush the pipe.

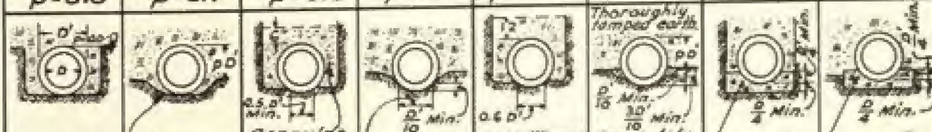
Figures 5-28 and 5-29 contain tables showing the approximate required strength for highway culvert or sewer pipe under various depths of fill. It should be noted that in table (A) the required strength listed must be multiplied by the diameter of the pipe in feet. This is because the increase in crushing strength with increased size of pipe only partly compensates for its greater surface area, against which pressure is exerted. In short, although large pipe is stronger in itself than small pipe, it is weaker in regard to burial loads.

The tables also indicate the importance of pipe bedding in determining strength. Corrugated pipe requires good compaction of fill at the sides and proper bedding.

It is questionable whether the formed bed shown for the ordinary and first class installations is often perfect enough to give the calculated support. However, careful tamping of the fill under the curve of the pipe will give similar results.

DRAINAGE & SEWERAGE - LOADING ON PIPES

TABLE A – REQUIRED ULTIMATE STRENGTH, LBS. PER LIN. FT., OF PIPE FOR VARIOUS DEPTHS UNDER H-20 HIGHWAY LOADING.



DEPTH OF COVER OVER PIPE (feet)	BEDDING CONDITIONS							
	IMPERMISSIBLE		ORDINARY		FIRST CLASS		CONCRETE CRADLE	
	p=0.0	p=0.7	p=0.0	p=0.7	p=0.0	p=0.7	p=0.0	p=0.7
	Backfill untamped.	Not shaped to fit pipe.	Granular materials shovel placed and tamped.	Accurately shaped to fit pipe.	Backfill carefully tamped in thin layers.	Thoroughly tamped earth. Accurately shaped to fit pipe.	2000 # Concrete.	2000 # Concrete.
2	2430 D	2490 D	2280 D	2320 D	2250 D	2260 D	2190 D	2190 D
3	2060 D	2190 D	1840 D	1300 D	1770 D	1820 D	1700 D	1690 D
4	1880 D	2040 D	1580 D	1670 D	1500 D	1560 D	1400 D	1400 D
5	1760 D	2180 D	1390 D	1640 D	1290 D	1480 D	1160 D	1240 D
6	1820 D	2220 D	1380 D	1600 D	1260 D	1440 D	1100 D	1160 D
7	1900 D	2380 D	1390 D	1660 D	1240 D	1450 D	1070 D	1140 D
8	2050 D	2550 D	1460 D	1740 D	1290 D	1510 D	1090 D	1160 D
9	2200 D	3030 D	1530 D	1990 D	1340 D	1720 D	1110 D	1290 D
10	2350 D	3240 D	1610 D	2130 D	1400 D	1820 D	1150 D	1320 D
12	2650 D	3780 D	1770 D	2430 D	1520 D	2040 D	1210 D	1450 D
14	3020 D	4340 D	2000 D	2830 D	1710 D	2360 D	1350 D	1660 D
16	3390 D	5010 D	2210 D	3170 D	1890 D	2650 D	1500 D	1860 D
18	3780 D	5780 D	2470 D	3650 D	2100 D	3030 D	1640 D	2090 D
20	4170 D	6300 D	2700 D	3970 D	2290 D	3400 D	1790 D	2270 D

For depth greater than 20 ft., use Table B below. D = inside diameter in feet

EXAMPLE: Assume 24"ϕ pipe, depth 10 ft., ordinary bedding p = 0.7
Table A above: Ultimate strength per lin. ft. 2130 D = 2130 × 2 = 4260.
From page 5-21 select vitrified clay extra strength pipe or Class 2, Transite pipe.

TABLE B - MAX. HEIGHT IN FEET OF FILL OVER PIPE (NO LIVE LOAD).*

ULT. STRENGTH 3 EDGE BEARING LBS/L.F.	BEDDING CONDITIONS							
	IMPERMISSIBLE		ORDINARY		FIRST CLASS		CONCRETE CRADLE	
	p = 0.0	p = 0.7	p = 0.0	p = 0.7	p = 0.0	p = 0.7	p = 0.0	p = 0.7
1200 D	6.0	4.5	9.0	7.0	11.0	8.0	14.0	11.5
1500 D	7.5	5.5	11.5	8.5	13.5	10.0	18.0	14.0
1800 D	9.0	6.5	14.0	10.0	16.5	11.5	21.5	17.0
2000 D	10.0	7.0	15.5	11.0	18.0	13.0	23.5	18.5
3000 D	14.5	10.0	23.0	16.0	27.0	19.0	35.5	27.0
4000 D	20.0	13.0	30.5	20.5	36.5	24.5	47.5	36.0

NOTES FOR TABLES A & B: - In rock excavations an earth cushion less than 8" is classed as IMPERMISSIBLE bedding. ORDINARY & FIRST CLASS beddings require earth cushions of 8" minimum.

The values shown in the columns headed p = 0.7 should be used for projection ratios from 0.3 to 0.9 and those shown in columns headed p = 0.0 should be used for installations where the pipe is installed in a trench dug to a depth at least equal to the outside diameter of the pipe.

There is a difference of opinion in regard to the practicability of dishing the bed as called for under ordinary and first class conditions.

** From American Highway Practice by Laurence I. Hewes*

Fig. 5-29. Loading on pipes

Restricted Height. If there is not sufficient space between the channel bed and the embankment surface to install a round pipe of adequate size, two or more round pipes, or low clearance pipe with a flatter cross section or a pipe arch may be used.

Poured concrete structures may use a flat rectangle or two or more openings separated by supporting walls.

Multiple pipes should be parallel, and spaced at least half of their outside diameters, to facilitate tamping backfill. They should not be used for streams that carry coarse debris which might choke the openings.

Poured Culverts. Culvert barrels may be made of monolithic (one piece) structure of concrete poured into forms at the final location. This operation allows a wide latitude in sizes and shapes of barrels; allows a fairly exact proportioning of strength to load, and avoids problems sometimes met in procuring, transporting, and handling large pipe.

Poured culverts should always be reinforced. Even in casual construction when reinforcing bars are not available, the use of scrap metal or cable will both strengthen the structure and reduce the amount of concrete required.

A reinforced concrete barrel has great tensile strength and is unlikely to pull apart due to stresses in a settling fill. It can be made one piece with the sidewalls and wingwalls.

Relative costs of pipe and poured concrete vary with the locality, conditions, and in the case of concrete pipe particularly, with the distance from the manufacturer. In general, as the structure gets larger, pouring becomes more economical than concrete pipe. Remote areas and very high fills favor metal construction.

Small culverts carrying light fills usually have a square or rectangular barrel. When either the embankment or the stream bed is shallow in relation to the volume of water, two or more barrels or cells are placed side by side.

With increased depth of fill, or length of span, arch construction becomes more desirable.

Cost may be reduced if the same forms can be used for two or more structures. Knock-down steel forms can sometimes be rented for less than the cost of building them of wood.

Design and installation of poured concrete structures is a specalized field.

LAYING CORRUGATED PIPE

Handling. Corrugated pipe can be made up in any multiple of two feet. Lengths of eight to twenty feet are usually carried in stock, and longer or shorter ones are obtainable on special order. Shorter pieces can also be made by cutting with a torch.

Small and medium sizes are usually unloaded and placed by hand as in Figure 5-30, and medium to large ones lowered with a rolling hitch or with a crane. The crane may use a hitch around each end or around the middle with the help of a man to keep it balanced. Soft rope should be used so as not to scratch the galvanizing.

Pipe should not be dragged around on abrasive ground, nor scratched or banged against anything, as such abuse will damage the galvanizing and shorten the life of the metal.

It is lowered into trenches in the same manner as it is unloaded.

Foundation. The base should be shaped to fit the lower part of the pipe as closely as possible, by cutting the ground to shape, or building up with well tamped fill. The work can be checked by placing and removing the pipe, and noting whether it was in full contact.

If the floor is rock, it should be cut from six inches to three feet below pipe grade, the depth depending on the height of fill to be placed, and backfilled with earth or pea gravel. If it is mud, space should be

Fig. 5-30. Handling corrugated pipe

allowed for enough pea gravel to stabilize the surface. Saplings or wire lath might be laid under the gravel to provide extra stability.

If one end of the culvert is to rest on fill and the other in a cut, the fill under it should be thoroughly tamped to avoid unequal settlement. If the cut is rock, its edge should be beveled to distribute any settlement strains over a longer piece of pipe.

Placement. Each section should be placed with the longitudinal seams at the sides. The cross joints should have the external part of the overlap upstream so that if the joint is not tight, seepage will tend to move into the pipe instead of out of it.

If the pipe has a metal date tag, or an instruction tag, it should be on the upstream end of the pipe.

Joints. Sections are usually fastened together by a one piece band. This is placed under the end of the first piece, and the second laid so that the band will overlap each by the same number of corrugations. The coupler is then drawn tight by turning down the nuts with a wrench.

This joint resists any force tending to pull it apart, being about as strong as the pipe itself. If the pipe will be subject to very severe stress, a two piece coupler riveted to one or both sections may be used. The pipes are placed so that the collar lines up, and it is fastened with the bolts and nuts.

If the pipe is large enough to work inside (36" or more ordinarily, but less if a small worker is available), a one piece band may be installed in the regular way, and holes then drilled through the band and the pipes, and bolts used to strengthen the joint.

If water tightness is important, an asphalt sealer may be placed inside the band before installing, or a special coupling may be used.

Strutting. Large corrugated pipe may be strengthened against heavy loads by strutting. This consists of deforming it so that it is higher than it is wide. It is usually done by putting beams and soft compression caps along the top and bottom, pushing them apart with heavy jacks, and placing pre-cut struts to hold them in position.

Joints are made and fill placed and compacted in the usual manner.

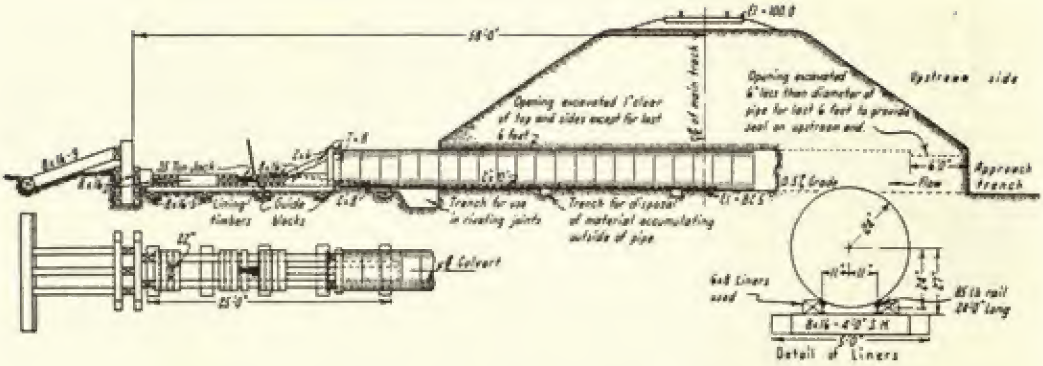


Fig. 5-31. Jacking pipe through fill

Struts are removed after a settlement period of three to six months, except that if the pipe shows a tendency to bend beside the head beam, or floods are expected, they are taken out immediately.

The pipe will then tend to resume its round shape and, in doing so, will press heavily against the fill on each side, further compacting it. This extra compaction, which is roughly proportional to the load carried by the pipe, gives additional support against flattening.

Paved or coated pipe is strutted at the factory before treatment. It is elongated with beams and jacks, which are removed after the sides are tied together with cross rods or wires. Paving or coating is then added.

These pipes are usually tamped in until the wires do not have tension, but not until they are perceptibly slack. Struts are cut when they have served their purpose.

Side Assembly. In rush jobs, where traffic is stopped or detoured inconveniently during work, the pipe sections may be assembled nearby, and carried, pushed, or dragged into position. If pushed by a bulldozer, the front should be held slightly above the ground by a crane, other machine, or a crew of men.

Jacking. Corrugated pipe can be pushed through an ordinary fill without trenching.

Figure 5-31 shows a diagram of this process. An approach trench is dug to line the pipe up, and a heavy backstop built. A trough is made across the trench, at the toe of the fill, for access to the pipe for riveting joints.

A wood frame is placed against the pipe and is pushed by jacks based on the backstop.

If the pipe is large enough, a man or men can work inside it, digging enough from the face to allow the pipe to be pushed ahead. Dirt may be loosened ahead of smaller pipes by augers, or, less commonly, by water jets.

LAYING CONCRETE PIPE

Handling. The standard length of concrete pipe is four feet, except for land tile. The pieces may be unloaded by rolling each pipe so that it will fall from the truck endwise onto soft ground or a couple of old tires. Bell-jointed pipe should be dropped on the straight end.

Pipe up to two feet may often be rolled and pried into place by laborers with bars and poles. However, in any size it is more convenient to use some sort of hoist.

Pipe can be handled by any lifting device with power to pick it up, and enough reach and maneuverability to place it easily. A crane is most suitable for placing it in a ditch, and a dozer shovel for laying it in the open.

A pipe hook, Figure 5-32, is very useful. It permits holding the pipe at the free end, and avoids difficulties in balancing it on a chain or sling, and in disturbing the pipe after it is laid by withdrawing the chain. (A) is alloy bar, 2″ x 4″, for pipe up to 60″. In (B) 4″ iron pipe will handle 24″ concrete safely.

Care must be taken not to let the hooked end of the pipe rest on anything, as contact might tip it so that it would slide off.

Eight foot lengths may have a two inch hole through the wall at the center. These can be picked up by means of an eyebolt inserted in the hole and caught inside with a nut and washer.

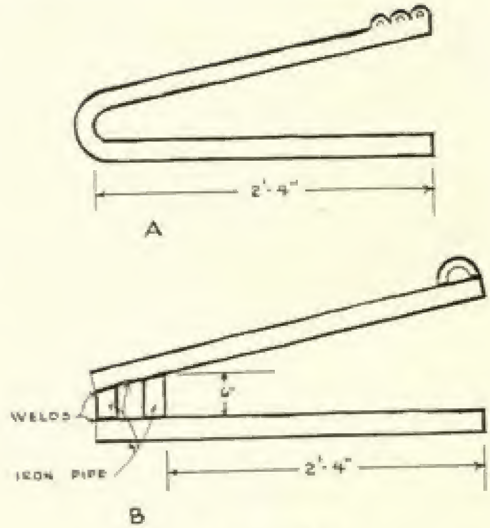


Fig. 5-32. Pipe hooks

Foundation. The base is shaped and tamped in much the same manner as for metal pipe.

If the pipe is to be laid in running water, leveling of the bottom for each piece may be difficult. A weighted plank or a wood trough may be placed on the bottom and carefully leveled and blocked up. Straight-sided pipe can be set on this and only minor adjustment should be required.

If the load of fill or traffic is to be heavy, or the foundation is partly on fill and partly on rock, or is unstable, a concrete bed may be used. A stiff mixture of concrete, as wide as the trench, or in forms a foot or two wider than the outside diameter of the pipe, and one-quarter of the pipe diameter in depth, is placed on a well-compacted earth base. It is roughly hollowed for the pipe which is settled into it by rocking, or slight raising and lowering.

Bell joint pipe requires cross grooves in the bed to accommodate the oversize end.

Placement. Pipe is usually laid with the bell or female ends upstream. If this is the case, placement should start at the downstream end. The first pipe can be lowered level, but the others should have the male or free end slightly lower so that it can be guided into place without scraping on the bottom. This tip is arranged by inserting the hook only part way into the pipe, or by pushing down on the free end.

If a section is not held in proper position by the bed, it should be chocked securely with stones or blocks until several more sections are laid, or the culvert is completed. This makes it possible to make any necessary readjustments with less work than if fill is tamped in immediately.

It is difficult to get each joint tight without considerable practice. However, it is often possible to lay several loosely, and then push them together from an end. This mav be done by a small dozer in the trench, or by a cable threaded through the culvert to a crossbeam.

Joints. Except in informal or temporary work, joints should be cemented. This is particularly important if water may pond above the outlet so that it will go through under pressure, which might force it out through open joints and cause softening and channeling of the embankment.

Small pipe is cemented by wetting the ends to be joined, and troweling a rich mortar on the upper half of the male side and the lower half of the female. It is desirable to rotate the free pipe slightly, after it is in position, to spread the cement

Fig. 5-33. Cable ties on concrete pipe

evenly. The outer surface of the upper two thirds can be troweled off.

If the pipes are large enough for a man to work inside, the whole culvert may be placed dry. Oakum is then hand tamped into the joint cracks, and cement or bituminous mortar applied from the inside.

Ties. If foundation conditions are such that the fill may spread and pull the pipe apart at the joints, the culvert may be held together by heavy, deep based headwalls, or by tie lines.

Tie lines may consist of three rods, cables, or chains, hooked around the end pipes. Turnbuckles or loadbinders are used to tighten them. They may be internal, or external as shown in Figure 5-33.

The inside ties will reduce culvert capacity slightly, and may cause jamming of debris and complete stopping. However, they are accessible for inspection and tightening. Outside installations are difficult to service.

A loose cable is sometimes left inside a small diameter culvert for use if it becomes plugged with silt. Pulling the cable back and forth will make a small hole which can be enlarged by forcing water through.

OTHER FORMS OF CONSTRUCTION

Wood Culverts. Culverts may be constructed of wood when they are for temporary use, or when time or expense prohibit obtaining more permanent materials.

Construction may be to almost any desired strength. Life expectancy will vary with the type and size of wood, preservative applied, and moisture conditions. In general, the parts which are permanently wet will have a much longer life than those which are exposed to air.

Several designs are shown in Figure 5-34.

Casual Placement. There are many situations in which it may be unnecessary or impossible to place culverts with the care required for permanent installations. These would include light traffic driveways and farm lanes; pioneer or access roads to be used for only a short period; and urgent construction in which it is necessary to get traffic through without delay, even at the cost of possible repair or reconstruction later.

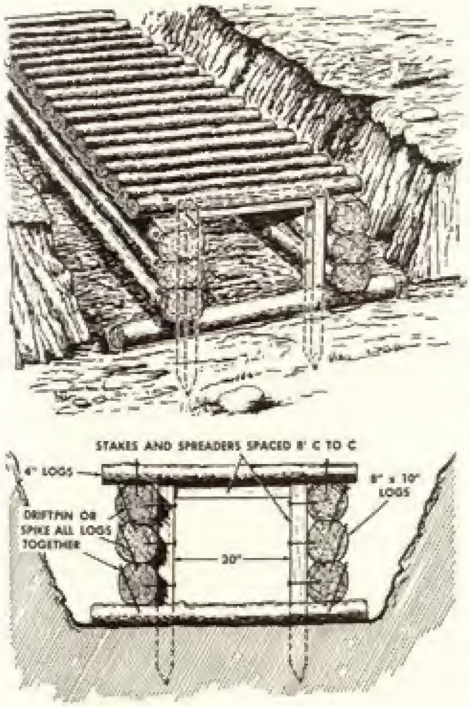
Good standards should be approached as closely as possible, however.

If heavy traffic will ride directly on the pipe, or very close over it, a strong construction should be used. If silting and trash are not a problem, several small pipes will be better than one large as they are more resistant to concentrated loads, and they can be provided with an adequate depth of cover more readily.

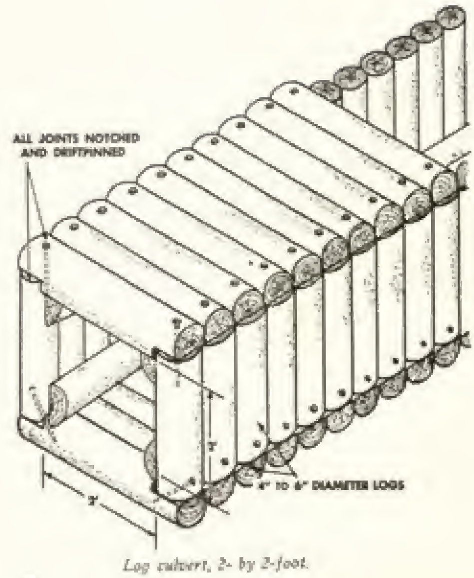
If the foundation is unstable so that a part of the culvert will sink, oversize pipe may be used to provide adequate capacity after settlement and silting. If silting can be prevented, a badly sagging pipe may act as an inverted siphon.

The pipe should be long enough not to require large headwalls, unless they can be easily built with big stones or logs available on the site. Wingwalls, where required, can be made of rocks, of saplings hammered in as piling, or of brush mats.

On wet bottoms, pea gravel or crushed stone should be used under the haunches. Ordinary earth can be used as soon as

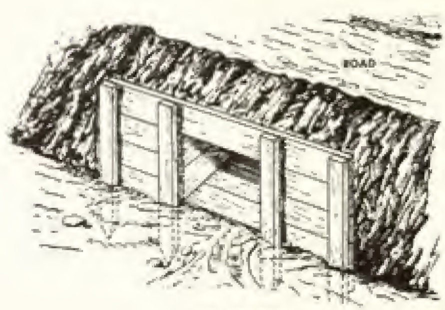


Log culvert, 30-inch.



Log culvert, 2- by 2-foot.

Backfilling a log culvert



PLANK HEADWALL

Courtesy U. S. Army Engineers

Fig. 5-34. Wood culverts

the gravel has been built up above water level, but it will not consolidate under water.

BACKFILL

Proper placing and compacting of backfill affects both the strength of the pipe and the load it has to carry.

Load Distribution. If a round pipe lies on a hard flat surface, and is subjected to load, the entire pressure falls on the line of bottom contact. If the surface is curved, the area of contact is greatly increased, and the load per square inch reduced correspondingly. As the haunches curve upward, the amount of vertical support to each square inch of surface decreases until it is zero at the widest point.

Corrugated pipe is flexible and requires horizontal support as well. A normal load tends to flatten the top and spread the sides. If the sides are held in firmly, the arch form of the load-carrying section is retained and strength kept at a maximum.

No part of the foundation or backfill touching a flexible pipe should be rigid, as

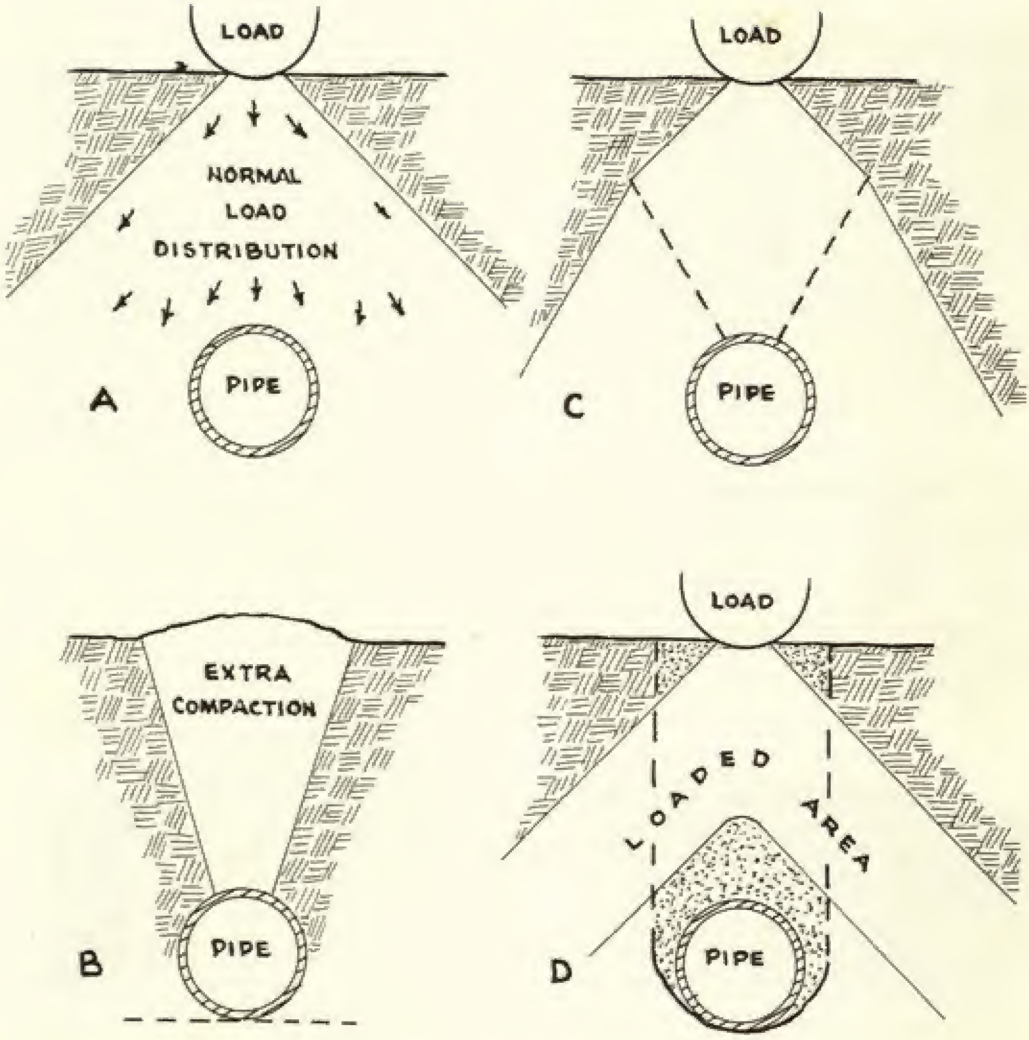


Fig. 5-35. Load over pipe

the whole pipe should be able to change cross section shape as it deflects under load, and any rigid support will cause excessive strains, particularly at the edges of the contact.

Rigid pipe receives only nominal support from the side fill.

Surface loads on soil masses are ordinarily distributed over increasing areas on lower levels, as in Figure 5-35 (A), so that pressure per square inch diminishes rapidly. If there is a difference in bearing power of the soils within the affected cone, the more rigid soil may carry most or all of the load.

In (B) backfill has been placed loosely over an exposed or projected pipe. Settlement under traffic, or from the effects of weather, will be a fraction or percentage of its depth, so that the thinner fill over the pipe will not sink as far and will project as a surface ridge. This ridge may receive heavier loads, and be more thoroughly compacted, than the soil on each side.

If the surface is then bladed smooth, as in (C), the more compacted soil will trans-

mit most of its loads straight down to the pipe, rather than allowing them to spread out through the softer fill to each side.

Loose backfill may have similar behavior in a wide trench. In a narrow one, however, loads will be carried by the firmer undisturbed walls, as in (D). This arching effect will relieve the culvert of part of the weight of the upper soil, and of traffic.

If a trench is loosely filled, settlement will result in a surface trough. Vehicles bumping across this will cause heavy impact loads. If the pipe is near the surface, it may be damaged or destroyed. If deep, the loads will be largely carried by the walls.

A tightly tamped backfill should distribute loads evenly over the whole area and subject the culvert to normal loads for its depth, as in (A).

Whatever load is imposed on the immediate vicinity of the pipe will be shared by it and by the fill on each side. If the fill is tightly tamped, it will bear a larger part of the burden, relieving the top of the pipe. Vertical pressure on the side fill is partly converted into horizontal pressure against the sides of the pipe, providing support for the top load.

Tamping. Fill must be tamped under the pipe haunches. It should be free of lumps, stones and trash, and should contain enough moisture to pack, but not enough to make it rubbery. It is placed with a hand shovel in thin layers.

The tamper should have a narrow edge to enable it to get well under the pipe, and, if the trench is narrow, may require a curved handle.

Filling and tamping are done evenly on both sides of the trench, to avoid shifting the pipe to the side. It may be necessary to wedge it in place temporarily with rocks or other blocking. Such material may be left and buried if the pipe is rigid, but removed if it is flexible.

Tamping blows should not be so vigorous as to wedge the pipe up out of position.

When sufficient fill has been placed so that its surface is out from under the pipe, mechanical tampers can be used. Fill should be compacted to the full width of the trench, or, if the pipe is on the surface (projection condition), for one pipe diameter on each side. Layers should be four to six inches deep.

When the pipe is nearly or wholly covered, layers of six to twelve inches may be placed, and tamping continued, until the trench is filled to grade.

Side Fill. When an embankment is to be built up on each side of the pipe and above it, much of the compaction can be done by machinery first moving parallel with the pipe, then across it.

A roller working parallel must be kept far enough away so as not to exert a horizontal thrust that will move the pipe. Fill and compaction should be kept even on both sides. Since there is often only one roller available, and it may not be able to get across, the other side may be compressed with a truck or by tamping.

Soil between the rolled strips and the pipe, and between the rolled strips and over the pipe, must be thoroughly tamped.

Successive layers can be rolled closer to the pipe center line. It is good practice to postpone crossing it until the fill is as deep as the outside diameter of the pipe, to avoid pushing it out of line.

Material is pushed to the pipe by a dozer or grader.

Loose Backfill. The fill may be built up to a depth equal to pipe outside diameter, then ditched directly over the pipe. The trench is filled in loosely, and layers of compacted fill built to the top of the embankment in the regular manner.

The soft fill over the pipe causes the load to be transferred to the solid sidewalls.

If the original trench is backfilled by a dozer, care should be taken not to drop big rocks on the pipe.

FORDS AND DIPS

Farm or pioneer roads sometimes cross a shallow stream on its bottom so that vehicles must drive in the water. This type of crossing is called a ford. It may be satisfactory for light or occasional traffic, but it is subject to interruption by high water and ice, and may develop bad bottom conditions which would be difficult to remedy.

Crusher rock, in mixed sizes from ½″ to 2½″ makes a good patching and paving material. If bank gravel is used, thorough raking will allow the water to take away excessive fines.

In arid regions, many watercourses are dry most of the time, but will occasionally carry such large volumes of water that adequate bridges would be very expensive. In such cases, the road may run across the channel at its natural grade, with no provision made for passing water under it. The section of road in the channel is usually heavily built, reinforced concrete slabs up to two feet in thickness sometimes being used. This slab should be sloped on its upstream side, and may have a cut off or curtain wall extending below its main mass.

Occasionally a culvert may be placed under or beside the dip to pass small water flows, or a culvert structure may include a spillway for flood water.

Second-class roads may cross such a stream bed on graded local material that must usually be worked over after each flow of water. Roads may also run considerable distances in stream beds, as this may be the only route which is practicable without heavy blasting and grading.

SOIL MOISTURE

Water Table. Subsurface water exists in three states or zones. The lowest of the series is hydrostatic or free ground water. Its upper surface is known as the water table, or ground water level. It follows the contour of the land in a general way, but tends to be farther under the surface in hills and pervious soils than in hollows and heavy soils. If it rises to or above the surface, it makes swamps, ponds, or springs.

The actions of this water are controlled by gravity, causing it to seek lower levels by the resistance of the soil to its movement, and by fresh supplies of water reaching it from the surface.

The water table may be static, or fluctuate only slightly, or it may shift up and down widely in response to season or rainfall.

Soil which is saturated with ground water is usually unstable under load, will turn to mud if disturbed, and does not permit the growth of roots of most plants.

If a hole is dug below the water table, it should fill with water.

Capillary Zone. The capillary zone lies above the water table. It may be a few inches deep in coarse sand, and eight feet or more in heavy soils. It contains a substantial quantity of water that is held above the gravity surface by capillary attraction and other forces tending to attract and hold it in the finer soil spaces.

The amount of contained water diminishes from the bottom to the top of this zone.

Capillary movement in coarse soils is rapid, in fine ones quite slow.

Raising or lowering the water table may raise or lower the capillary table.

Medium and fine soils in this zone usually contain too much water for stability, and may be subject to frost heaving. In climates where rainfall exceeds evaporation, this zone offers the best conditions for root growth. In arid regions, the water may deposit alkali in the soil and render it unfit for cultivation.

Upper Zone. The upper or hygroscopic zone contains water which is in very thin films on the particles, or is in chemical or physical combination with them. Some of this water is hygroscopic—absorbed from

the atmosphere—and is greatest in amount when humidity is high.

These small quantities of water often give the soil maximum stability, by acting as a cement or binder. Much of the water is too firmly attached to be removed by plant roots, or any method but oven baking.

This zone may also contain varying quantities of rain water, moving downward by gravity or capillarity, or adhering to soil particles. This is available to plants and may be found in sufficient quantity to make the ground unstable.

SUBSURFACE DRAINAGE

Purpose. Subsurface drainage lowers the water table. Deep drains, or those in porous soil, will lower the capillary surface also.

Soil must be drained when its water content makes it incapable of supporting roads or other structures on it, or causes frost heaving.

Playgrounds, golf courses, and other recreation areas may require draining to dry up spots which remain wet and soft long after rains.

Farmland drainage may serve to eliminate wet spots that cannot be worked as early as the surrounding land; to speed up the drying and the warming of soil in the spring; to encourage plants to form deep root systems, with resulting increase in vigor and drought resistance; and to leach out harmful substances which may accumulate in the soil.

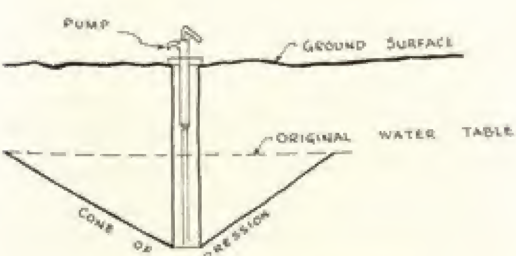


Fig. 5-36. Cone of depression

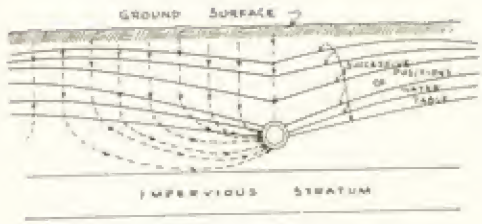


Fig. 5-37. Ground water movement

Methods. Ground water level may be artificially lowered by open channels or ditches, or by buried pipe or porous material. Such pipe is generally referred to as tile, even though it might be made of other materials.

In soils that will stand on steep slopes, ditches are the most economical construction down to a depth of a few feet. When wide cuts must be made to produce stable slopes, or when greater depth is required, the open ditch may involve so much excavation as to be more costly than tile.

Ditches, together with any space required for spoil, or for protection of machinery against falling in, may occupy a rather wide strip of land. In farm land, they cut up the fields and add to the expense of planting and cultivation. They are hazardous when near roads. In any location, they will require occasional culverts or bridges for crossings.

Ditches usually require maintenance. This may include removing silt and cave-

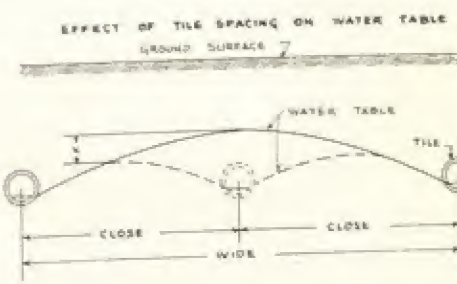


Fig. 5-38. Effect of tile spacing

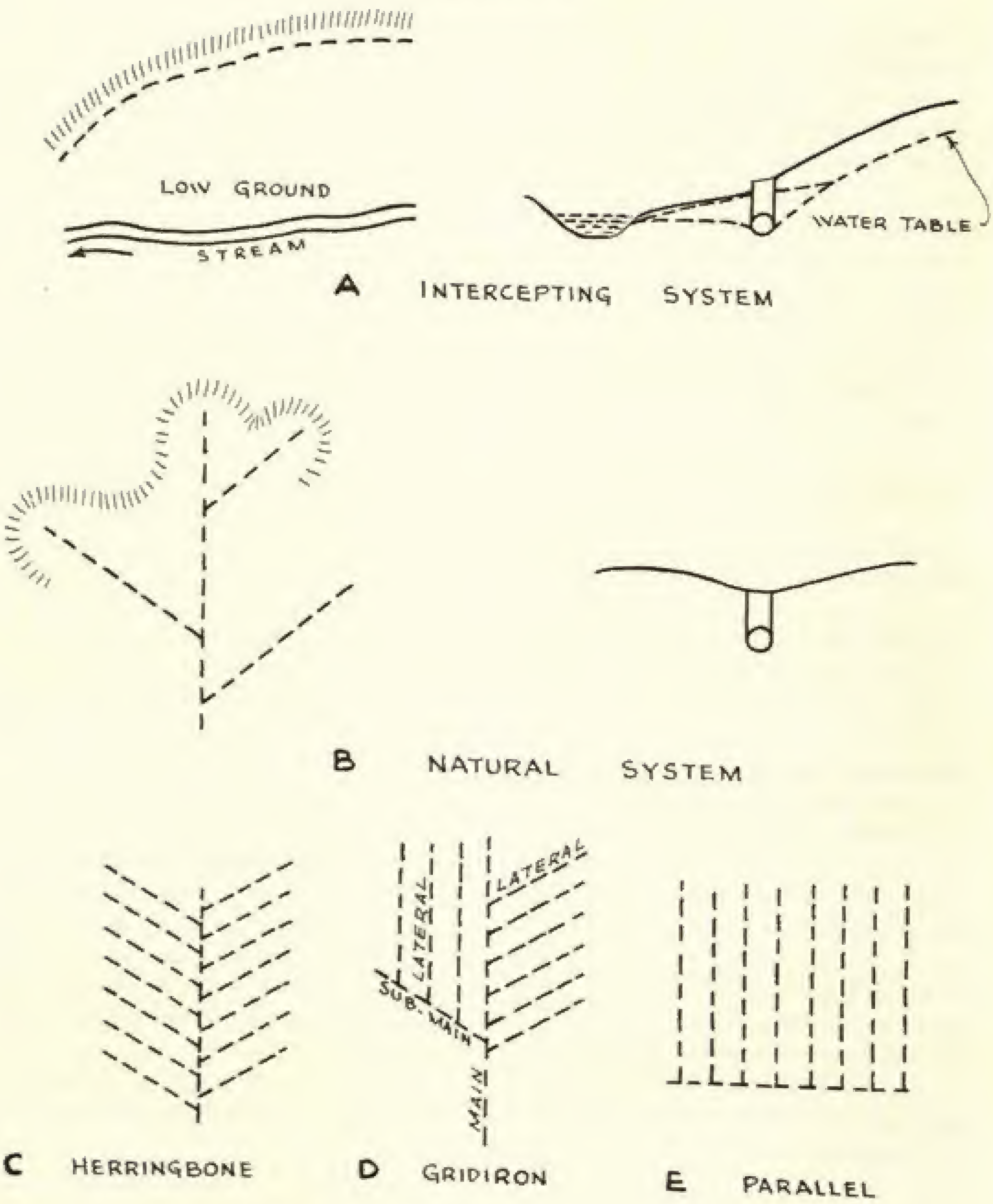


Fig. 5-39. Subsurface drainage patterns

ins, repairing erosion damage, and cleaning out vegetation. Neglect may result in general deterioration, with eventual stoppage, or expensive re-digging and clearing.

Buried drains do not cut up the fields, nor offer hazards along roadsides. However, if one becomes plugged, as a result of poor design, improper installation, or accident, it may be difficult and expensive to locate the difficulty. If the stoppage is due to general silting, it will probably be cheaper to lay a new line than to dig up and clean or repair the old one.

Choice of the type of drainage will de-

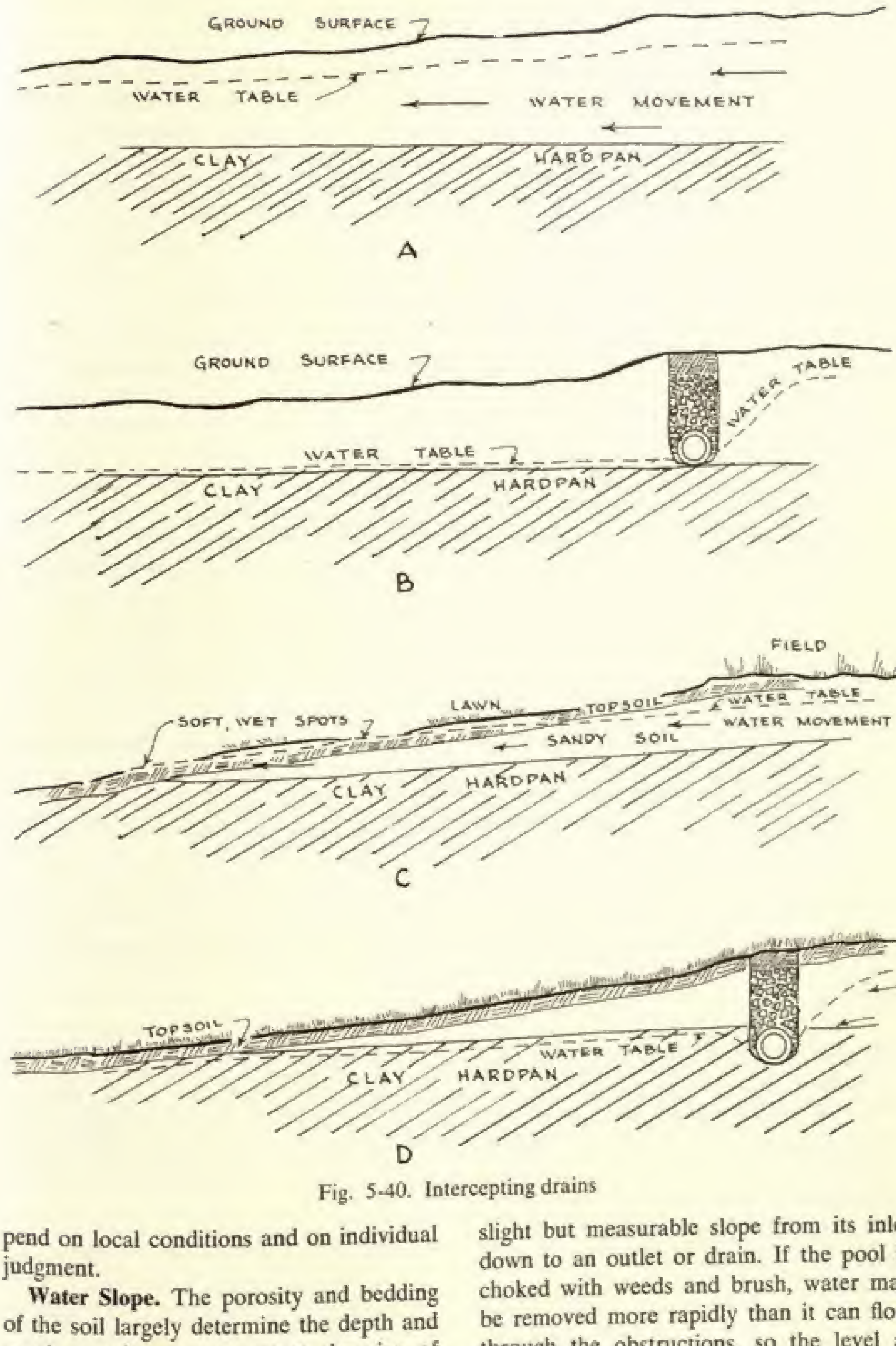


Fig. 5-40. Intercepting drains

pend on local conditions and on individual judgment.

Water Slope. The porosity and bedding of the soil largely determine the depth and spacing and to some extent the size of drains required for a given project.

A pool of surface water will assume a slight but measurable slope from its inlet down to an outlet or drain. If the pool is choked with weeds and brush, water may be removed more rapidly than it can flow through the obstructions, so the level at the drain may be several inches below other parts of the pond as long as flow continues.

LOCATION OF LATERALS

AVERAGE AGRICULTURAL PRACTICE

Soil	Depth in inches	Spacing in feet
Irrigated land	60 - 100	125 - 1,000
Peat	42 - 60	75 - 200
Sand	42 - 48	100 - 400
Sandy loam	36 - 48	100 - 250
Loam	36 - 48	40 - 100
Silt loam	36 - 48	35 - 80
Clay loam	30 - 48	30 - 66
Clay	30 - 48	20 - 40

Fig. 5-41. Depth and spacing of drainage tile

The water table may be considered to be the surface of an underground pond, obstructed in its flow by soil particles. If these particles are coarse and loosely fitted, the spaces will be large enough to allow some freedom of flow, and the slope up from an outlet of the water surface will be gradual. If the soil is fine grained and compact, the spaces will be so small that flow will be almost stopped and the gradient down to a drain point will be very steep. This slope is called the hydraulic gradient.

Slopes will usually be steeper after rains and in wet seasons than when the surface is dry.

If the drainage is to a single pipe opening in uniform soil, the drained area will assume the shape of an inverted cone, called the cone of depression. See Figure 5-36.

If the drainage is to a ditch or porous horizontal pipe, the shape will be a trough of roughly triangular cross section. The water surface and movement are shown in 5-37, and effects of spacing in 5-38.

Drainage Layout. Figure 5-39 shows the standard patterns used for subdrainage. Where practical, the intercepting or curtain drain is the most economical. Figure 5-40 shows two types of condition where it should be used.

The natural system involves use of the natural drainageways for ditch lines, and involves minimum excavation. Difficulties may be unfavorable surface conditions for ditching; irregular pattern which duplicates in some spots and is inadequate in others; or excessively crooked lines.

The herringbone, gridiron, and parallel systems are best suited to level or evenly sloping land. The choice will depend largely on which will most readily provide best gradients in the lines.

Depth and Spacing. The table in Figure 5-41 gives general recommendations for depth and spacing. They cannot be strictly followed in every case because of wide variations in conditions. Tile should at least be below the frost line and danger of crushing by machinery.

When a field is first tiled, the widest permissible spaces may be used, and additional laterals added later if they are required.

French Drains. These drains, also called rubble or blind drains, consist of a rock fill in the bottom of a trench, as in Figure 5-42, with finer material over it, to prevent dirt from working down. The usual practice is to put the large rocks in the bottom.

The more elaborate ones in (A) and (B) will serve the same purposes as open joint pipe, but the others are not suitable for water carrying sediment, as the lack of concentrated flow will allow the spaces to fill up until the drain is blocked.

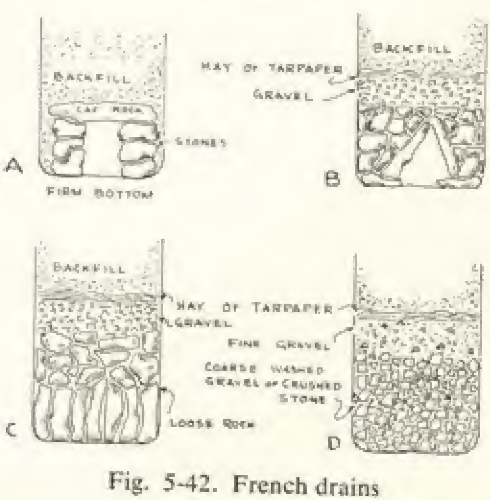


Fig. 5-42. French drains

Corncobs, sawmill scrap, and other coarse waste may be used instead of rocks.

French drains are used chiefly where there are abundant supplies of suitable materials, and their short life expectancy is outweighed by the saving in purchase of pipe. Labor costs on a carefully constructed drain will probably be high, but a dump filled one may be quite inexpensive.

These drains may be used partly to dispose of stone raked out of gravel, or otherwise appearing during construction work.

Moles. Certain types of stiff plastic soils may be drained by opening pipe-like channels in the soil. This is done by attaching a mole, which is a metal piece shaped like an elongated egg, to the heel of a subsoil plow, as in Figure 5-43. The plow is set to penetrate to the desired depth and the mole is dragged through the ground. It pushes the soil aside and compacts it. Under favorable conditions these tubes will stay open for five years or more, and may open permanent channels. In other conditions, they may close immediately or within a few months.

Drainage is usually to a stream, ditch, or hole. The mole is dropped in this and pulled straight into the bank and lifted out at the upper end of the run.

A tile or metal pipe screened with coarse mesh wire should be placed in the outlet to protect it against erosion and plugging by entrance of small animals.

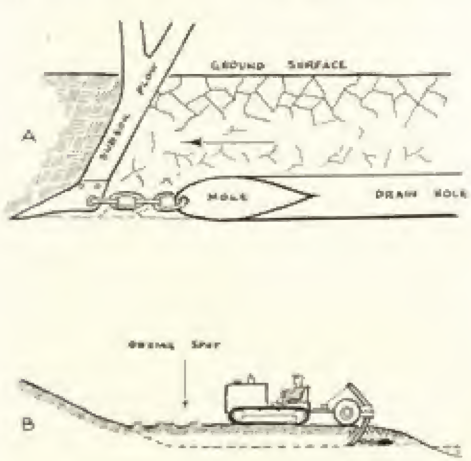


Fig. 5-43. Mole drainage

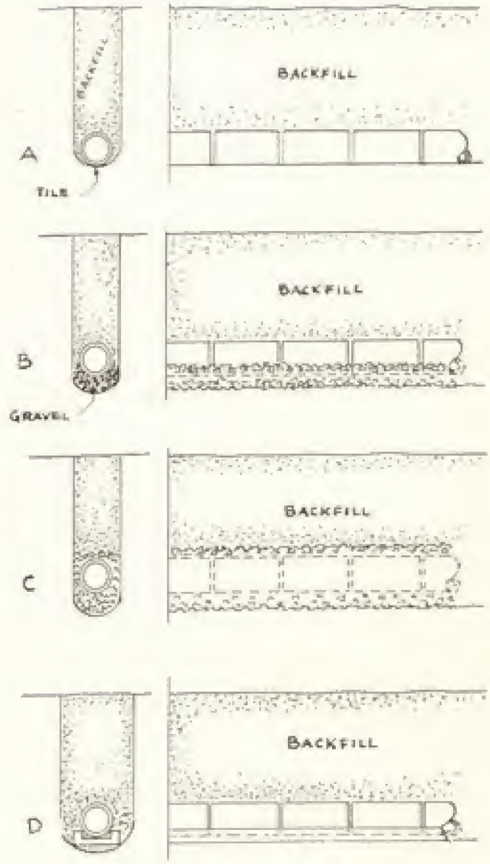


Fig. 5-44. Tile drains

TILE DRAINS

The simplest type of drainage by underground tiling is shown in Figure 5-44 (A). A trench is excavated, the bottom smoothed to the desired gradient, butt joint land tile may be laid with ends touching, or with spaces up to ¼", and the trench backfilled.

Water from the affected area drains into the tile through the joints, and to a less extent through the walls and flows inside the tile to the outlet.

Under favorable conditions, such a drain may function for a very long time. However, dirt falling in through the joint and entering with the water may fill it up, or

plug low spots left by subsidence of the ditch bottom.

In (B) the tile is laid on a bed of gravel. This provides a firmer foundation and provides a porous space into which dirt can drop through joints from the pipe. This storage space for silt may fill so that the pipe will ultimately fill also; but it may serve to trap all dirt brought in during a period of adjustment, after which little or no dirt will move.

In (C) the pipe is surrounded by gravel, which preferably should be a mixture of pieces ranging from coarse sand to ½″ crushed stone. This serves to filter dirt out of incoming water, keeps loose dirt from reaching the pipe joints, and provides a good bedding.

Tar paper or hay can be used in connection with any of these techniques. It can be laid over the pipe where it prevents dirt from falling in, particularly when a large opening is caused by misalignment. The joints may be wrapped individually, or covered by a continuous strip.

It may also be placed over a gravel topping to prevent soil from working down into it. The under surface of the dirt often becomes so well stabilized that it will not cause trouble after hay has rotted out.

When the tile is laid on a curve, the wide spaces at the outside of the joints should be covered with pieces of broken tile.

Connections of branch lines may be made with sewer tile "Y's" or tees, or by junction pits which may be made large enough to serve as line cleanouts. A "Y" provides a smoother flow and larger water capacity than a tee of the same size.

Cradling. If the ground is muck, or otherwise unstable, the tile should be supported by boards, as in (D). Cleated boards supporting the haunches are preferable to flat boards because of better support and more permanent alignment.

Corrugated metal pipe may be used instead of tile and cradles.

Laying Land Tile. A large part of the land or drain tile used is in farmland. The work is usually on a fairly large scale, on regular grades and with adequate space. Costs must generally be kept to a minimum.

Ditching machines are particularly adapted to a rapid sequence of operations.

Small machines, with buckets as narrow as six or eight inches, may be used for depths up to four feet. These involve minimum excavation and assure lining up of tile. As the maximum depth is approached, it becomes more difficult to place tile accurately, and very difficult to remove stones or earth that may fall from the sides. It is usually not possible to use a tile laying shoe. It may be inconvenient or impossible to place gravel or tar paper with the tile.

Wider buckets will eliminate these difficulties, but will increase the amount of excavation and backfill.

The tile supply is laid on the field, parallel with the ditch line, just far enough to clear the ditcher, on the side away from the intended spoil pile. Pieces are placed

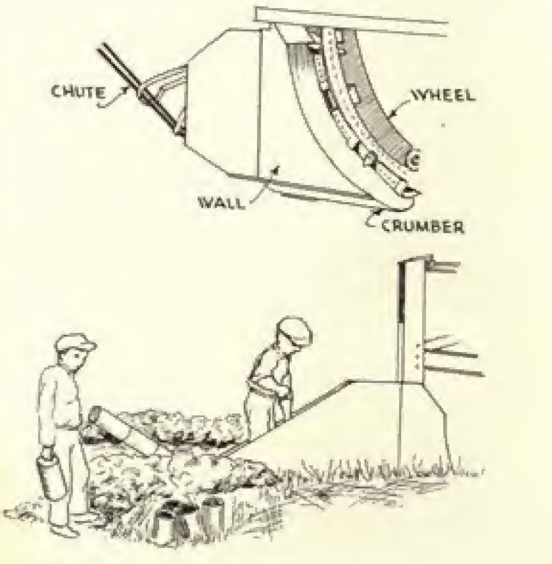


Fig. 5-45. Tile laying shoe, fed from top

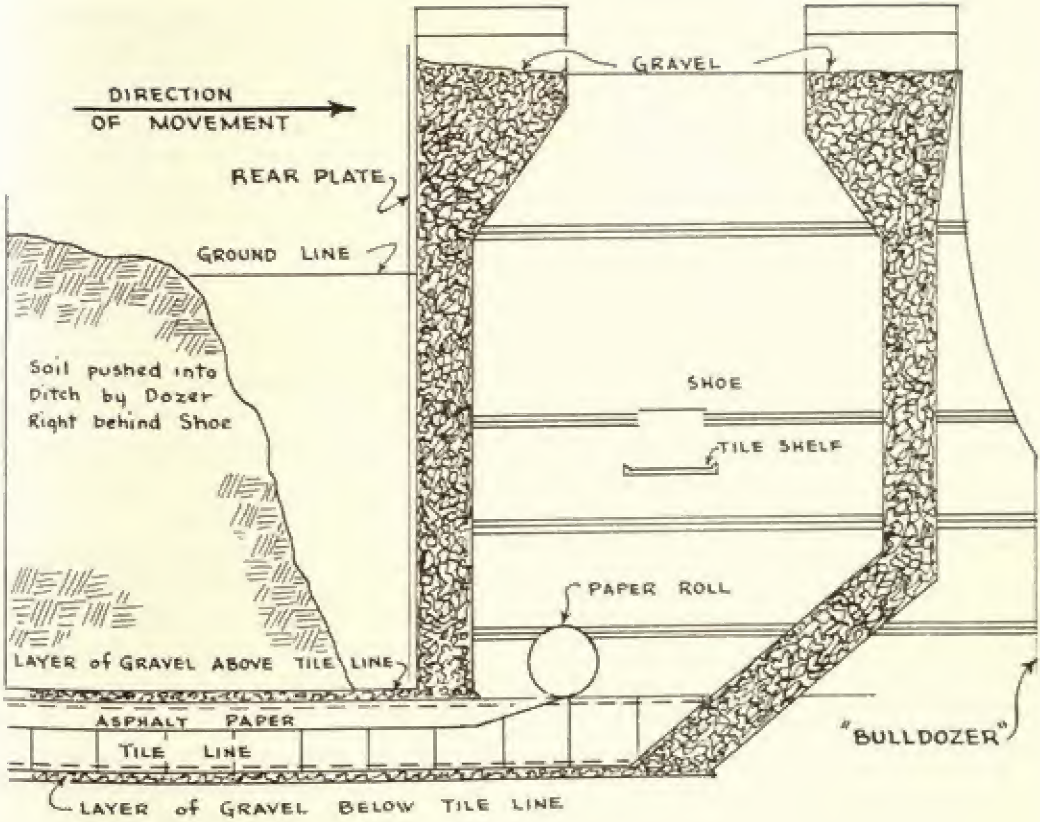


Fig. 5-46. Tile shoe, man inside

end to end to give the correct number, with a few extra placed at frequent intervals to make up for broken or imperfect tiles.

The tile should be placed on the ditch bottom immediately behind the ditcher to minimize the danger of "losing" the ditch through caving of the sides. The first tile should be plugged with a stone or half brick to protect the line against entrance of dirt or animals. Pieces are usually picked up and placed with an L-shaped rod of light iron. A curve bottom ditch will tend to center them, but they must be checked for alignment anyway.

Tar paper, if used, should be in a narrow continuous strip in a roll, laid over the tile.

If the ditch is wide enough to work in, the tile may be laid in the same manner or by hand. In the latter case, a picker may be used to supply tiles to the ditch man.

Gravel is sometimes laid under or over the tile by a dump truck with a small opening in the rear gate, similar to that used for supplying automatic sand spreaders. It straddles the ditch. The gravel may pour by gravity, or may be raked or shoveled down the body floor by the man controlling the gate opening.

It is important to smooth off a bottom layer of gravel before placing tile.

Tile Boxes. If the ground is not firm enough to stand until the pipe and accessories are laid down, a tile-laying box or shoe must be used. A number of varieties are available, many of them of only local distribution.

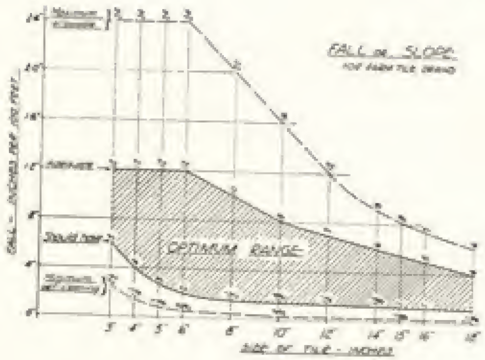


Fig. 5-47. Tile slope chart

A tile box should be slightly narrower than the bucket side cutters. It includes the bulldozer or crumber attachment which smooths the ditch bottom behind the buckets, a pair of parallel walls which will slide between the ditch walls, and a chute on which tile may be placed to be fed by gravity or manual control into the ditch bottom.

Figure 5-45 shows a simple type of box that is operated from above.

A more elaborate box in which a man can work, and which permits placing of tile, bottom and top gravel, and tar paper, is shown diagrammatically in Figure 5-46. This is suitable for the greater depths required in irrigated fields.

Two gravel hoppers are mounted on the box, front and rear. A roll of tar paper is mounted on an axle across the inside of the box. The tile layer sits near the bottom, his back to the "bulldozer," a cleaning blade which follows the wheel. The tiles rest on a shelf in front of him, and are replaced as he uses them by a man standing on the box, who picks them up with a rod.

As the ditcher moves forward, the blade smooths and shapes the bottom of the ditch. The front hopper spreads a strip of gravel on the bottom. The thickness of this strip is regulated by raising or lowering the hopper spout. The tile is laid on the gravel, with the ends touching. The tar paper rolls off its spool to cover the pipe and the rear hopper deposits gravel on it.

The bottom of the rear plate may be curved to smooth over the top of the gravel, or may be set to ride several inches above it. A dozer works immediately behind the machine backfilling. This is necessary, for if the ditch is allowed to stand open an appreciable time, one of the walls might move horizontally and slide the tile out of line.

The gravel may be piled beside the digging line, outside of the tile string, and placed in the hoppers by a small tractor front loader. A hydraulic control clamshell bucket is more efficient than the regular loader bucket, as it picks up the gravel without pushing it around.

A tile box is best adapted to wheel ditchers as they do not disturb its digging balance. Attachment to a ladder ditcher is possible, but is more difficult as it tends to pull the bottom of the ladder backward and upward.

Backfilling. In agricultural work, it is customary to backfill with the soil dug from the ditch after placing the pipe and whatever porous material is required. However, if it is to act as an intercepting or curtain drain, imported porous material—such as gravel, sand, or corncobs—may be used to near plow depth. A top layer of native soil should be used to prevent surface water from washing in with its probable burden of silt and trash.

Whatever type of material is used next to the tile, it may be advisable to place it carefully by hand until there is no danger of the pipe sections rolling out of alignment. Compacting it immediately over the pipe (blinding) may reduce silting.

Gradients (Fall or Slope). Figure 5-47 indicates graphically the most desirable gradients for land tile of various sizes. It will be noted that up to 6" diameter a maximum of one percent is desirable, over two percent is not permissible, and that larger sizes require flatter slopes.

Steeper slopes may give sufficient velocity

AREA IN ACRES DRAINED BY TILE WITH GIVEN DIAMETER AND SLOPE

PERCOLATION = 3/8" IN 24 HOURS—COEFFICIENT OF ROUGHNESS, n = .013

TILE DIAMETER IN INCHES	FALL OR SLOPE — FEET PER 100 FOOT STATION				
	.10	.20	.30	.50	1.00
4	3	4	5	7	10
5	6	9	10	13	19
6	10	14	16	22	31
7	15	22	27	34	48
8	22	32	39	50	71
10	41	58	71	92	130
12	67	96	118	153	213
14	105	149	182	235	333
15	127	179	218	283	400
16	149	211	260	336	473
18	209	295	360	467	660
20	280	393	483	625	880
22	360	510	626	800	1,140
24	453	643	794	1,020	1,440

Fig. 5-48. Area-tile table

to create eddies that will erode material below the joint, with possible undermining of the tile. This may result in stoppage, in blowing out to the surface, or in washing out of sections of line.

When steeper overall slopes are required by the topography, tiling may be done in a series of benches or levels, connected by inclines of sewer tile with cemented joints.

Flatter slopes increase danger of silting.

Tile Size. Figure 5-48 shows the number of acres that will be drained by tile of various sizes, at slopes up to one percent. Some of the sizes listed may not be generally available, and these figures are for average conditions.

It is good practice to use tile of larger than minimum diameter for a line so that effectiveness will not be lost as readily by silting or misalignment.

Surface Inlets. A tile drainage system may include one or more places where surface water can drain into it. The flow of water should be calculated and the tile increased in size to accommodate it.

Such inlets require careful design. They must be arranged so that dirt cannot be washed in, so that animals cannot enter, and so that hydraulic pressure cannot be exerted on the tile underneath the opening.

For example, if a six-inch inlet to a six-inch line is used, water ponding over it due to excessive rainfall may put hydraulic pressure on the underground pipe, causing too fast a flow and probable erosion.

If the inlet is choked down to three or four inches, or provisions are made for surface overflow, this difficulty should not occur.

Outlets. The tile line or system may terminate in a drainage ditch, a large drain system, a river, lake or sea, or in a sump. If a sump, an automatic electric pump should be used to keep the water level below the bottom of the tile to insure free drainage.

A projecting metal pipe may be used, as in Figure 5-49, or a masonry spillway, 5-50, to avoid bank erosion and an undermining. Since outfall lines often lie under surface channels, it may be necessary to make provision for surface flow also, as shown.

The outlet should be protected against entrance of small animals by coarse mesh wire, a grating, Figure 5-51 or an automatic gate, as in Figure 5-52.

A drainage system that ends in salt water between high and low tides, or in a waterway subject to flooding, should be fitted with a check valve or gate that will let the drain water out, but not allow the sea or flood water in. To make this effective, the last few feet of tile should be glazed and a concrete headwall used.

Corrugated Pipe. Perforated metal pipe may be used instead of tile. It is usually of light weight corrugated construction, with four parallel rows of $\frac{5}{16}$ or $\frac{3}{8}$ holes. Such pipe is light, tough, comes in long pieces, and is easy to lay, except in caving soil where a tile laying box is needed.

It is placed with the holes in the underslopes or haunches, as this position keeps silting to a minimum. It is good practice to use collars at the joints.

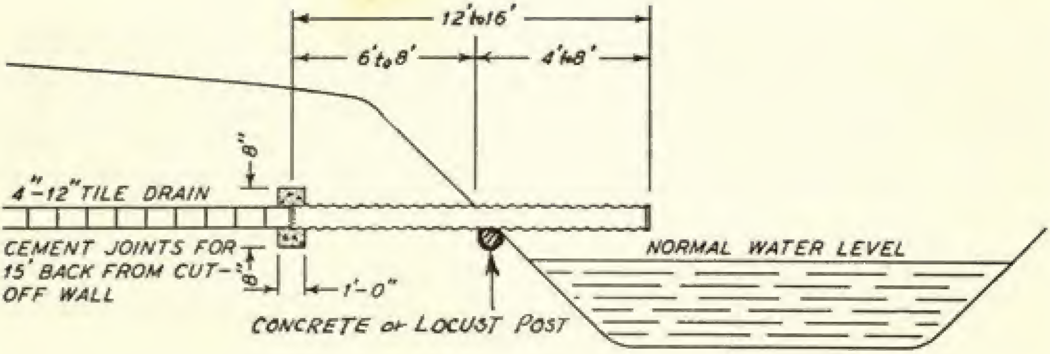


Fig. 5-49. Projecting drainage outlet

This pipe is too expensive for ordinary agricultural work, but is widely used for road subdrains because of its resistance to crushing and its dependable alignment.

Plugging. Tiles may become partially plugged with mud entering with ground water, particularly when no protecting gravel and paper are used. Flooded streams may also cause plugging, either by backing up the tile or causing the water to stagnate in them.

It is sometimes possible to flush tiles clean by utilizing a surface inlet, or opening the upper end and putting a large volume of clean water through. The flow should be started slowly, as a rush of water might move enough mud to form a solid block, which would necessitate abandonment of the line.

It usually is cheaper to lay new tile than to dig up and clean an old one, unless the stoppage is in a small area and can be located accurately.

SEPTIC DRAINS

Some drains have no open discharge but depend on the porosity of the soil through which they run, or in which they end. A common type is the septic field for disposal of domestic waste, a set of standards for which is shown in Figures 5-53 and 5-54. Septic tank overflow is carried in a sealed pipe to the head of the field, which consists of a number of lines of porous land

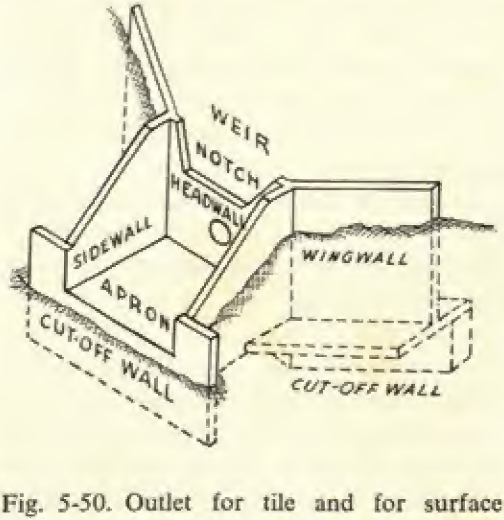


Fig. 5-50. Outlet for tile and for surface drainage

Fig. 5-51. Protected pipe outlet

tile with a maximum slope of one inch to 16 feet, with open joints on a base of graded washed gravel that is brought up the sides flush with the top. Building paper or hay is placed over this to prevent dirt fill from sifting into the spaces. Fluids in the pipe leak out at the joints and percolate through the gravel and subsoil down to the ground water. The gravel serves to widen the area over which the sewage can come in contact with the soil.

Purification is affected by microorganisms in the septic tank and in the soil.

For successful operation, a septic field must distribute the sewage evenly over an area large enough to absorb it completely. If the system is overburdened, or if some part of it carries too large a share of the total load, the fluids may force a channel and flow out on the surface.

Pervious soils absorb the sewage much more rapidly than tight ones, and can handle much larger quantities per foot of tile and square foot of trench.

The size of a system is calculated on the basis of volume of flow and the rate of absorption. For this set of specifications, it is figured there will be 100 gallons per person per day in residences. Day schools have a rate of 15 to 35, and restaurants and business buildings 10.

A percolation test is made on the soil. Holes a foot square are dug to the bottom level of the proposed trenches, and filled with water to a depth of two feet. The water is allowed to drain until it is six inches deep. The time required to fall to five inches is recorded.

This process is repeated until the drop from six to five inches takes the same time on two successive tries. This time is matched to the same or the next higher figure in column 1, Figure 5-54. The center column gives the absorption rate, the right hand one the number of square feet of trench bottom needed.

The tank should have a capacity of not less than 100 gallons per person. Any watertight construction may be permitted. Concrete block, special concrete slabs, poured concrete, and prefabricated tanks are used.

Fig. 5-52. Automatic outlet gate

Where a garbage destructor is used, 50% should be added to all capacities.

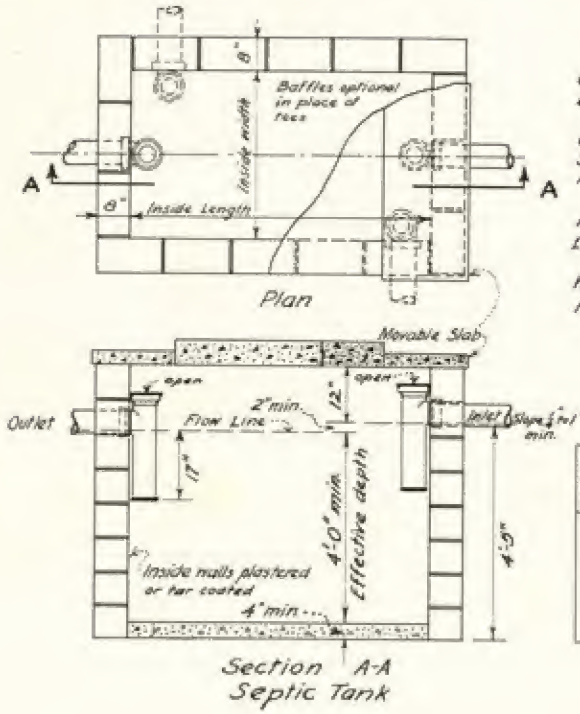
As with most permanent installations, it is good policy to be generous in figuring. The load might increase, or the soil might lose absorption efficiency.

The field should not be heavily shaded, and cannot be crossed by vehicles. It must be at least 25 feet from any pond or stream, and 50 to 100 feet from any drilled well or reservoir. It must not drain toward a surface well or spring used for household water, at any distance.

If the native soil is not suitable, or the water table is high, it may be necessary to install a curtain drain to divert water, or to haul in hundreds of yards of sand to construct a filter bed in which to lay the tile field. This can be expensive enough to be a determining factor in selecting a lot.

Local regulations should be consulted before arranging for sewage disposal, as methods vary in different areas and exact conformance may be required.

TYPICAL DETAILS FOR SMALL SEWAGE DISPOSAL SYSTEMS

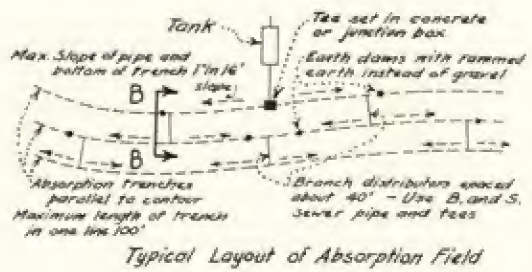


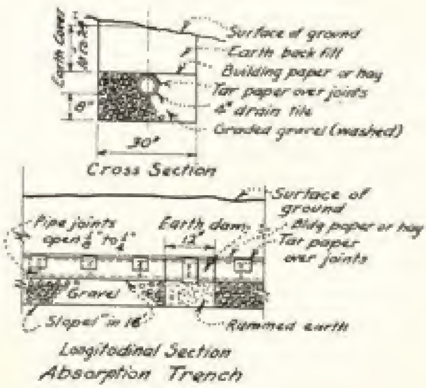
Tank Notes

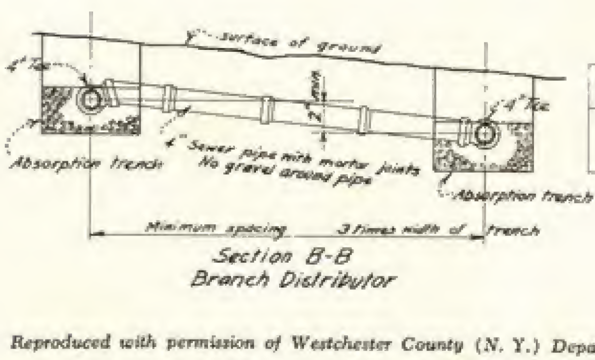
Overall inside depth - not less than 5 ft.
Depth below flow line - " " " 4 ft. nor more than 6 ft.
Outlet elevation - not less than 2" below inlet
Scum or air space - " " " 12" above "
Inside length - 5'0" minimum - not less than 1.5 nor more than 3 times width
Inside width - 3'0" minimum
Locate inlet and outlet as far apart as possible in opposite sides
Water tight construction
Provide removable slab top or manholes or cleanouts

Concrete Block Tank

Liquid Capacity Gallons	Inside Length	Inside Width	Blocks 8"x8"x16" 8 Courses
500	5'-4"	3'-5	120
600	6'-1"	"	128
800	6'-9"	4'-0"	144
1000	8'-1"	"	160
1200	10'-0"	"	184
1400	11'-4"	"	200







Gravel Quantities

Bottom Width	Depth under Pipe	Cubic Yards per 100 ft
18"	5"	4
24"	6"	6
30"	8"	9

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Fig. 5-53. Details for small sewage disposal systems

TIME FOR 1" FALL Minutes	TYPE OF SOIL	ALLOWABLE ABSORPTION RATE Gals. per Sq. Ft. per Day	BOTTOM AREA REQUIRED PER 100 GALS. OF FLOW * Square Feet
5 or less	Sand, gravelly loam	2.5	40 *
8	Light loam	2.0	50
10		1.7	60
12	Loam	1.5	67
15		1.3	76
22	Heavy Loam	1.0	100
30		0.8	125 **
60	Hardpan	0.6	165 **
60	Heavy Clay	None (Use other means of disposal)	

* 100 sq. ft. minimum per system. To estimate length of trench, multiply by 2/3 for 18 in. trench, by 1/2 for 24 in. trench, and by 2/5 for 30 in. wide trench.

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Fig. 5-54. Septic field data

Septic systems are used only where public sewers are not accessible, and are usually abandoned if a sewer is laid.

A drain may also terminate in a dry well. The well consists of a hole in the earth, filled with loose rock, rubble, or clean gravel. The pipe discharges into it, and the fluid soaks out of the sides or bottom, or becomes part of the general circulation of ground water. This system depends on pervious soil in contact with the dry well.

VERTICAL DRAINS

Vertical drains of sand or porous soil can be used to move water up or down. They are often made by drilling or blasting holes in an impervious layer lying over a pervious one. Figure 5-55 (A) shows a section of ground in which opening up the hardpan would allow water to drain into underlying gravel, and (B) shows a pond which is able to exist above the water table in a pervious sand, because silt and organic matter deposited from the water has sealed all spaces in a thin layer on its bottom and sides. Breaking this layer by any means will cause the pond to drain unless sufficient silt is stirred up to seal it again.

Vertical drains, through which water rises because of being displaced by the weight of fill, are used to stabilize deep layers of saturated peat. Such soils may contain 50 percent or more of water, and

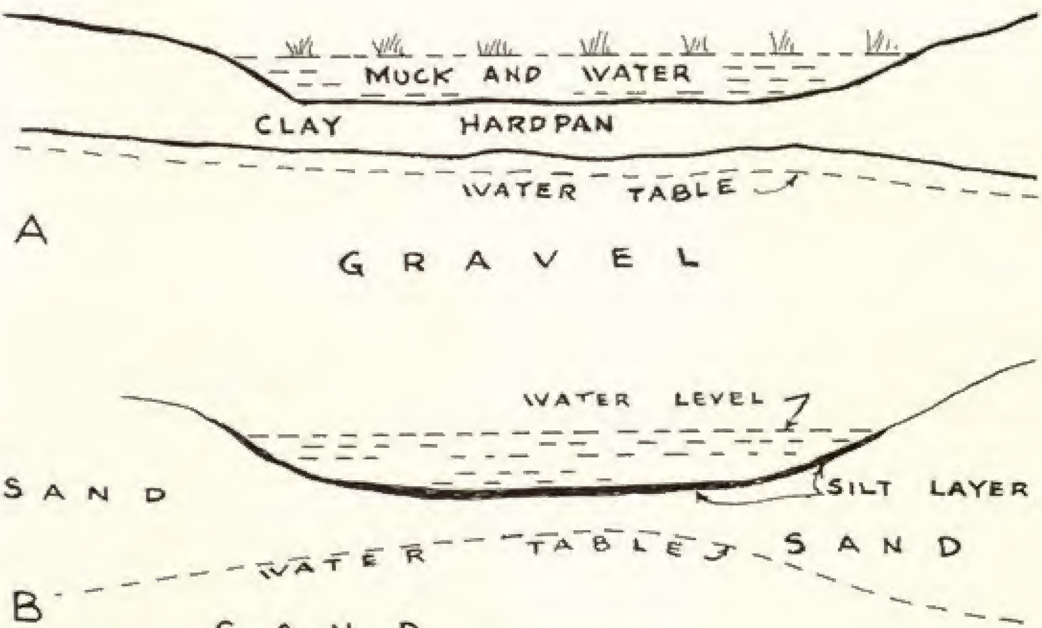


Fig. 5-55. Perched water tables

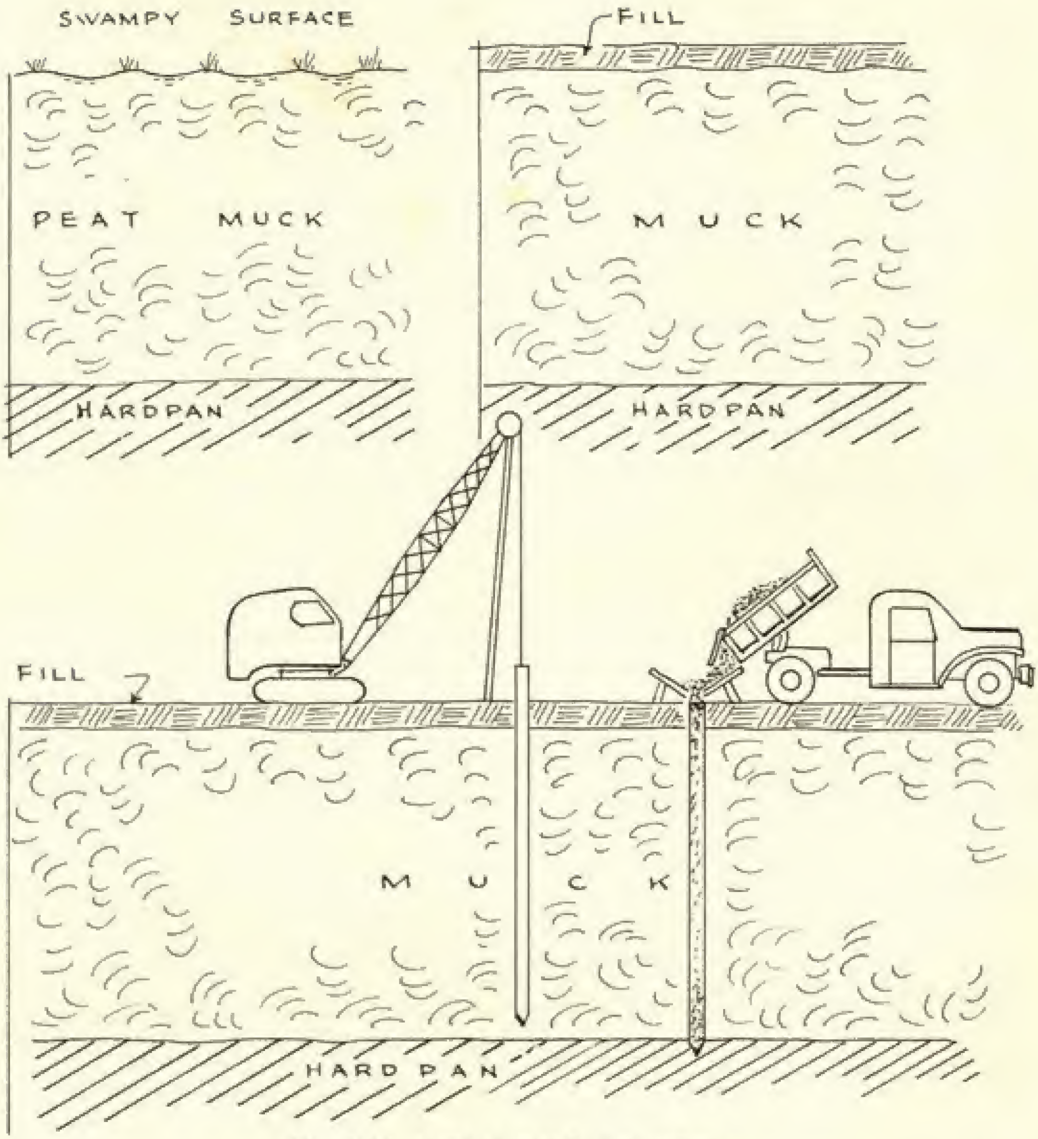


Fig. 5-56. Vertical sand drain installation

behave like viscous fluids under pressure. Fills placed on them sink, owing in part to water being squeezed out of the mud, and partly to the mud being displaced to each side. This settling of the fill may continue a great many years, and become so uneven as to make pavements or other structures on the fill become unusable.

The squeezing out of water may be accelerated, and the sideward movement of mud practically eliminated, by making vertical holes in the mud, filling them with clean sand, and connecting their tops with a drainage system, as indicated by diagrams in Figure 5-56 and 5-57. The fill is then placed and its weight causes the water to enter the sand columns and rise into the drains. If the columns are properly spaced, sufficient water will be removed to stabilize the mud enough to carry the intended load.

This technique is comparatively new and has not yet been reduced to a formula. Part

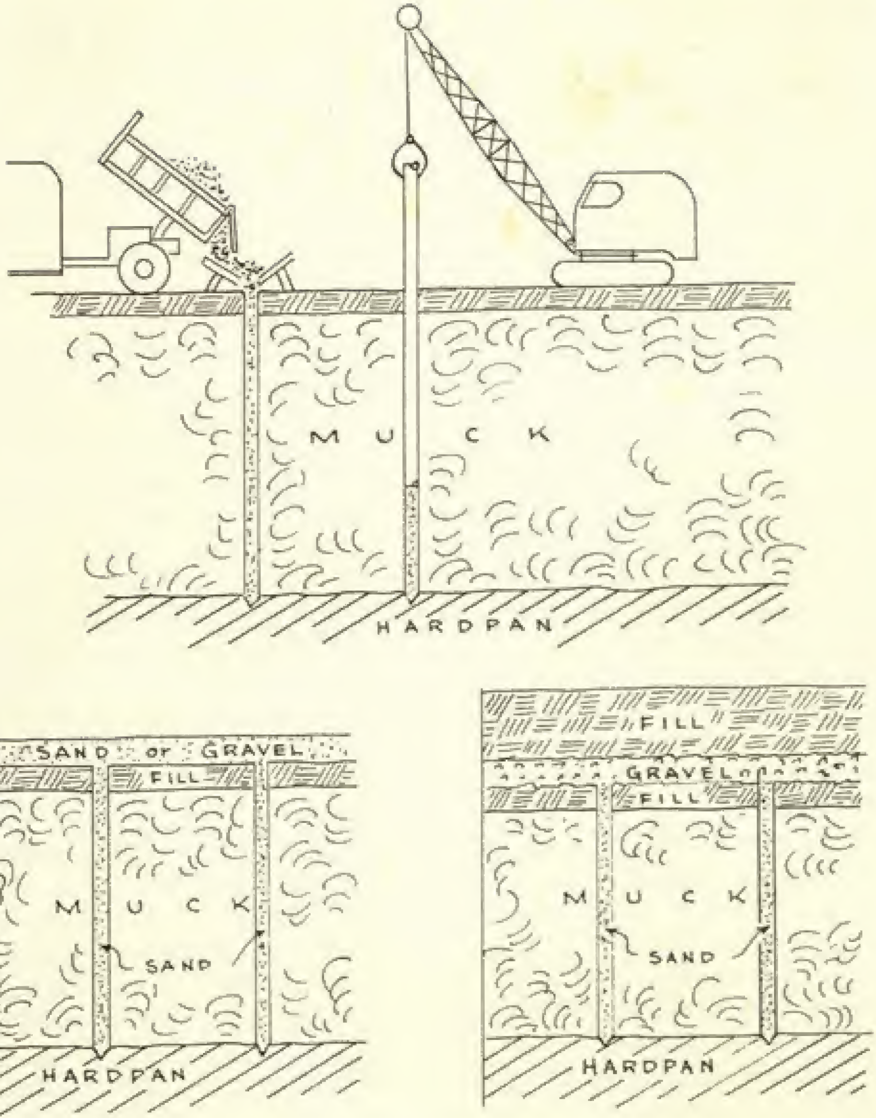


Fig. 5-57. Vertical sand drain installation (continued)

of the fill may be placed on the swamp, then the holes made by sinking a hollow walled pipe by jetting with water and compressed air, or by driving a hollow pile with a detachable head. In either case, when the tube has reached the bottom of the soft layer, it is filled with sand and pulled, leaving the sand in the hole. Hole diameters of 16 to 24 inches are commonly used, with spacing varying between 8 and 22 feet.

If the tube is pulled by conventional methods, the sand may stick to it and be raised sufficiently to allow mud to enter crevices in it and interrupt the drainage. This may be avoided by attaching an airtight head to the tube after the sand has been placed, and pumping compressed air between the head and the sand. This raises the tube but exerts an equal downward force against the sand and holds it in place and together.

The tops of the columns may be drained

by spreading a blanket of clean gravel or sand, a foot or more in depth, over the whole area; or by connecting the columns with tile or rubble drains. If the fill is all gravel, a drainage layer may not be needed.

Settling may be still further speeded by placing more fill than will be required for final grade. The extra weight will squeeze the water out of the mud more quickly. When settlement is judged to be complete, the extra fill is removed.

EXCAVATIONS

It is desirable to remove surface and ground water from areas to be excavated, but the cost may exceed the advantages gained.

Water may be removed naturally by seasonal change, or artificially by diversion, draining, siphoning, or pumping.

Seasonal Lowering. The seasonal fall of ground water level may be quite considerable in areas having dry summers. Some places which are so wet in winter and spring as to be very expensive to work, may become dry to depths of five to thirty feet. Permanent swamps may develop sufficient crusts to allow movement of machinery.

Such changes are not uniform, as a wet season may keep water levels abnormally high while an exceptional drought will cause extreme or unseasonable lowering.

When it can be arranged, it is obviously good practice to undertake wet excavation in a dry period, as any reduction in either mud or unwanted water will reduce costs. The economy is greatest in work in marshy areas and in shallow excavations, but may be noticeable even in deep work.

PUMPING

Dewatering of excavations commonly requires use of pumps.

If the water is small in volume or contains a heavy load of mud or other solids, a diaphragm pump is preferred. A centrifugal pump is needed for larger quantities.

A centrifugal pump should be placed as near the water level as possible. More energy is used pumping water over a high bank than over a low one, but the total lift may be largely determined by the job. However, these pumps will push the water more efficiently than they will pull it, and much better output will be obtained by keeping the suction line short.

A standard centrifugal pump is built to handle solid water and pumps air with difficulty. When the pump and inlet hose are empty, the pump must be filled with water (primed) before starting, and will then work for a while slowly drawing the air out of the inlet pipe. When the water is sucked into the pump its efficiency rises abruptly. If air is permitted to enter the intake, the pump will lose its grip and have to again slowly work up enough vacuum to lift the water into it. This process is fairly quick in new pumps, but in worn ones is slow if the lift is at all high.

Air leaks on the inlet side of the pump should be carefully guarded against. Threaded pipe connections should be treated with pipe dope and tightened firmly; bolted ones should have both faces of the coupling clean, a gasket and sealing compound used, and bolts tightened down well. Inspection ports should be well seated and sealed, and gauges and plug fittings should be doped and tightened. If the shaft from the engine goes through a packing box, the packing should be tight enough so that there will be no drip when the pump is stopped.

Even small air leaks may prevent a pump from picking up water, and large ones developing while running may cause it to lose its prime. A pump may also fail to work because of a clogged inlet pipe. It is very desirable to keep a vacuum gauge on the inlet side, as it will indicate the conditions of the pump. Low vacuum indicates air leaks, lack of sufficient water in the pump,

or worn or broken impeller and wear plates. Abnormally high vacuum indicates plugged intake line.

If the vacuum is low, but no leaks are found, wet clay should be plastered over all joints and possible cracks or fissures. This makes a good temporary seal for small leaks. The pump casing should be checked for cracks and the packing tightened.

Inlet Protection. The low end of the inlet pipe should be fitted with a screen which will prevent entry of any object large enough to plug the pipe or damage the pump. Water containing leaves or other fibrous matter will clog such a screen readily, and may make necessary the placing of an outer screen of quarter or half inch mesh, or some similar wire. This outer screen is best located far enough from the inlet so that water going through it will not have force enough to hold rubbish against it to block it. See Figure 5-58.

Another inlet problem is that of the pipe and screen sinking into a muddy bottom and becoming blocked, or being buried by soil washed over it. Placing the inlet in a wooden box will prevent sinking and make it easier for the pump to suck up washings.

In long inlet lines, or large ones, it is good to have a foot valve in the bottom to hold water in the pipe while the pump is not running, unless the pump is tight and the inlet under water at all times. This

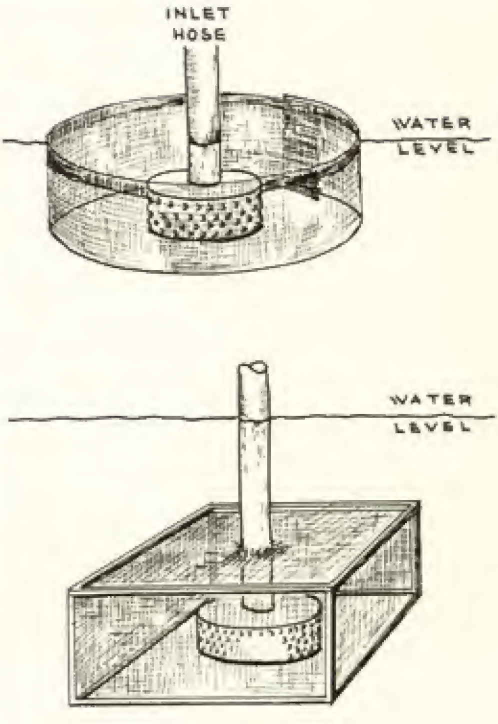


Fig. 5-58. Trash protection for inlet

will save time pumping out air each time the pump is started. Unfortunately, foot valves are subject to jamming and sticking, and may need frequent attention to keep them working.

A whirlpool may form over the suction end of the inlet pipe which will allow air to enter the pipe through several feet of water. This is most apt to happen if the

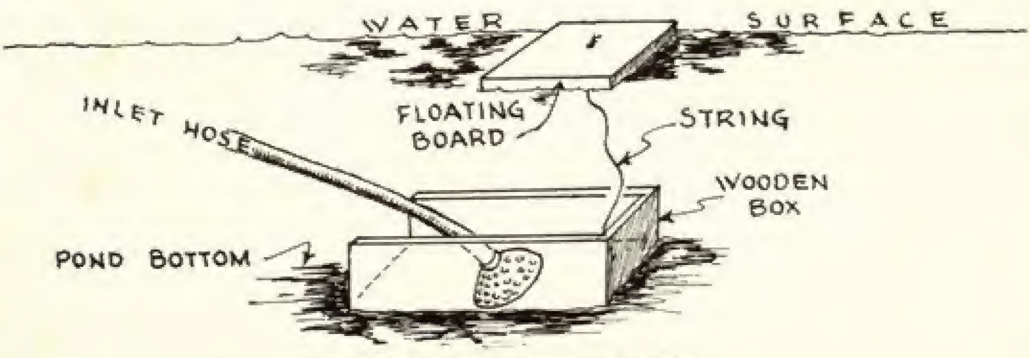


Fig. 5-59. Mud protection for inlet

pipe is lying in a nearly horizontal position. It can usually be prevented by arranging the end of the pipe to hang vertically or attaching a shield over the inlet, or by throwing a square or round piece of flat wood in the water, which will tend to center in the whirlpool and block the air passage.

A pump will work best if a foot or two of water is kept over the inlet. In most excavations, the bottoms should be kept as dry as possible. It therefore is advisable to dig a sump pit for the pump hose, and to cut through any ridges that prevent water from flowing into it from the pit.

Dirty Water. If the water flowing into the excavation is dirty, it indicates that soil is being brought in from outside the excavation. Continued pumping may cause caving of banks due to undermining; or even may cause sinking of adjoining buildings or roads. It is wise to keep such pumping to the minimum required for the work and to finish the job as rapidly as possible, even at extra expense. It may be necessary to dry the area by well points, or to block the water off by grout, chemicals, or freezing.

Contractors' liability and property damage insurance ordinarily does not cover damage to structures by undermining, even in the "comprehensive" policies. A special endorsement is necessary, and inspection of the job is usually required.

Well Points. A well point pump is a centrifugal pump with rather close fitting parts, and often with an auxiliary air-vacuum pump, and which can work efficiently in spite of a fairly high proportion of air in the intake lines.

A well point is a section of finely perforated pipe that is sunk into the ground by jetting, driving, or drilling. It is attached to ordinary iron pipe which rises to the surface and is connected by other lines to a pump, which usually takes care of a number of points.

When the pump is running, the ground water in contact with the well point is drawn through the holes or slits into the pipe and pumped away. The holes are so small that only very fine particles of earth will pass through them. The continued suction gradually removes all such particles from the area immediately around the pipe, leaving the coarser ones. This makes a porous screen with an outside area several times larger than that of the point, and improves its gathering efficiency.

Each well point will remove ground water from a cone of depression around it, the slope of which depends largely on the porosity of the soil.

If well points are placed in a line so that their cones overlap, a continuous band of soil can be dewatered, as in Figure 5-60.

A ditch could be dug in this band without encountering ground water, regardless of otherwise saturated conditions throughout the area.

The well points may also be set in a square pattern to dry up the ground for a cellar or similar excavation. It is sometimes possible to dewater such an area by using points as a curtain drain where the source and depth of the water are known.

In order to eliminate mud difficulties, the points should be placed deep enough so that the excavation will not reach capillary water standing above the artificially lowered water table.

In a deep excavation, it will be necessary to reset the well points and pumps on successively lower benches as the digging progresses, because of the inefficiency of high suction lifts. This may be done by starting the excavation oversize so as to leave a shelf at the bottom of each cut for placement of the pumps and lines, as in 5-61.

Well points are most efficient in porous soils and will ordinarily not give good results in clay soils. In peat, the points are jetted down and sand dumped in the hole around them to increase contact area.

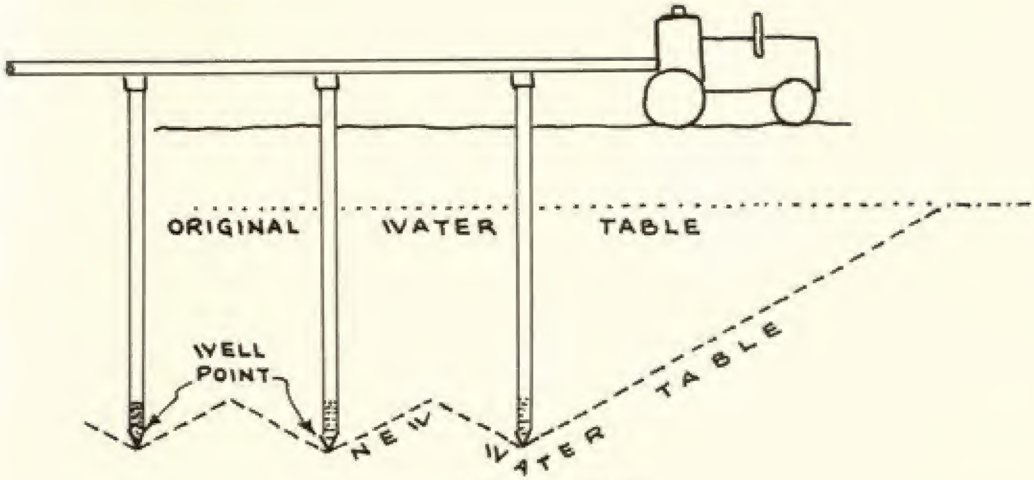


Fig. 5-60. Well points

Proper use of well points involves considerable work in placing, connecting, and moving points, and pumping is usually on a twenty-four hour a day basis for the duration of the job. In addition, considerable experience is desirable in order to avoid wasted time and possible failure to keep the job dry. It is generally advisable to subcontract this work to specialists.

Deep Hole Pumping. An excavation area may be predrained by sinking a number of shafts, lined with timber or pipe, and pumping from the bottom. The pumps used are usually small with electric motors. The shafts are more widely spaced than well points and can be used to much greater depths. Drilling and lining is expensive.

Deep well pumps, of the piston or the jet type used for water supply, may be used if equipped with good sand filters.

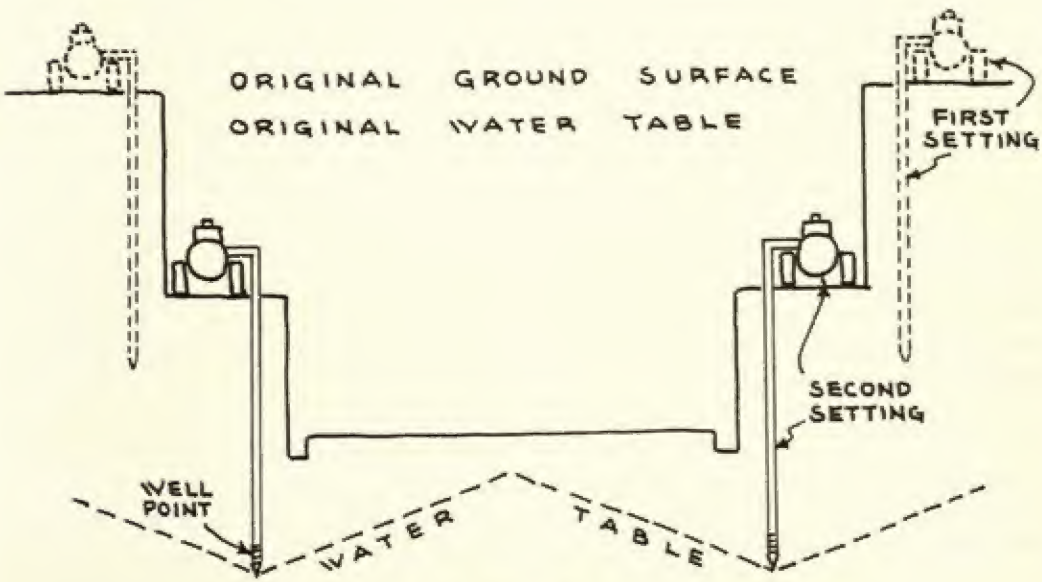


Fig. 5-61. Deep well point pumping

Sump Pumping. Shallow layers of soil may be dried by digging a deep hole in the area and keeping it pumped out. Effectiveness and promptness of drying may be improved by a system of ditches draining into the sump. These may run along the outside edges of the site and into the interior in any convenient pattern.

This is an excellent and inexpensive way to dewater a swamp before digging a pond, unless the flow of water into the area requires an excessive amount of pumping during the drying process.

Jetting. Jetting with high pressure water, or less commonly, compressed air, is used in making deep narrow holes for setting piles, installing vertical drains, obtaining soil samples, and for various other purposes.

Pressures required range from a few pounds for penetrating loose fine deposits to several hundred for tough clays.

A single pipe with a nozzle or reduction in size at the tip may be used in probing for rock or other obstructions. The tip reduction increases the velocity of the water and makes plugging less likely if it is forced into soil which the water will not cut.

Single pipe holes are irregular in shape, as the exhaust water and spoil rise around the pipe and will erode channels along the path of least resistance.

A better system is to use several water jets around the rim of a pipe so that washings can rise through the pipe to the surface. Water may be supplied through separate pipes, or by welding one pipe inside another, leaving a space between them for passage of water from an upper inlet connection to the bottom jets.

There should be at least three jets, preferably four or more. They must be evenly spaced around the circumference to prevent the pipe from drifting sideward toward the most effective erosion.

The pipe should be handled by a crane or some other type of hoist.

The lower end is sometimes fitted with teeth, and is lifted and dropped to loosen hard materials. The nozzles must be well protected against contact with hard dirt if this method is used.

CELLAR DRAINAGE

Excavating contractors are often consulted about the feasibility of having a cellar under a house. The problem may be one of the cost of dealing with rock on the site, or a fear of water conditions which would make the basement wet and unusable.

If proper procedures are followed, a cellar can be kept dry in any location where water does not spill in the windows or over the top of its wall. The cost ranges from the sometimes nominal expense of installing subdrains, up to thirty or more cents a square foot (1954 prices) for complete waterproofing of floor and walls.

Soils and Locations. The tight soils such as clay or the various varieties of hardpan tend to become saturated in wet seasons, even near hilltops. The quantity of water they may carry, which is the basis for deciding on drain size, may be very difficult to determine in a dry season. In general, if the soil contains long streaks or tubes of sand or very fine pebbles, it may be assumed that there is considerable flow through it. If there are spots near the house site which ooze water in the spring, or in which water-loving plants grow, a serious drainage problem is indicated.

Difficulties are sometimes avoided by shifting the house site to a spot with better drainage, or doing only shallow excavation and obtaining depth by filling around the walls. Drains should still be used as ground water may rise into the fill.

Subdrainage. Drainage around the footings is a precaution that should always be taken if there is any lower point to which water can be led. A porous soil such as

sand or gravel can seldom hold enough water to wet a cellar, but it may be part of a waterlogged lowland or a gradual slope up from one, or have water held in it by layers or sills of clay.

The standard cellar subdrainage consists of a line of land tile laid completely around the outside of the footing, and preferably a foot to eighteen inches below cellar floor level. It should be laid in a fine crushed stone, protected with tar paper or hay, and backfilled promptly. Such tile has a downward pitch of one-half to one percent from a point opposite the outlet.

The outlet may be land tile, but because of the danger of entrance of plant roots, glazed sewer tile with cemented joints is better. It should slope down away from the house at one to five percent grade to a disposal point. This may be a storm water drain under the street, a stream, or lower ground.

A storm water drain complication is that water entering the system at higher levels may back up through the tile and saturate the ground around its walls temporarily.

When there is no storm water drain, or connection to it is considered unwise, a discharge point on the same property should be sought. It is often easy to get permission to lay pipe through a neighbor's yard, but impossible to get a formal easement to keep it there.

A pipe having an open discharge should always be kept covered with coarse screening to prevent animals from entering it. If the pipe is large, a flap gate can be used, but these are not satisfactory in small sizes.

In many situations an open flow of water from a pipe is objectionable. In such cases the drain may lead into a dry well, or into tile laid out in the same manner as a septic field. An overflow exit may be provided, or the water may be left to work that out for itself.

Standard practice calls for four inch tile around the foundation. This is often too small, and its inadequacy is the cause of endless trouble. Even a small house can block a considerable area of horizontal movement of ground water, which will try to enter it unless it is drained off. After a heavy rain, a previously unnoticed seepage vein or group of small channels may carry more water than a small tile can hope to accommodate, and the foundation wall may cut into a number of them. Six inches is a safer minimum size.

The outlet drain can be the same size if the slope is steeper, or the next larger if it is the same.

If the house is on a slope most although not necessarily all of the water will be against the upper wall or walls, and may require eight to twelve inch pipe. If there is a long slope above the house, surface water may constitute a serious problem that is best solved by leading it through gratings and vertical pipes to the footing tile, which may then be as large as twenty inches. The size needed can be figured in the same way shown earlier for culverts, plus a liberal allowance for underground flow.

The floor should be laid on four to eight inches of crushed stone or gravel. This should be connected to the outside subdrain by a tile through or under the footing. If less gravel is used, one or two lines of tile might be laid under the floor. The gravel will serve to catch any vertical seepage of water, and will insulate and strengthen the floor also. The tile serves only for drainage.

Gutter leaders can be tied directly into the footing tile, emptied into nearby dry wells which will ultimately drain into it, or provided with dry wells or outlets at a distance.

If they dump directly into the tile, it must be large enough to carry easily all the water that will enter it from the ground and from the gutters. If the gutter water tries to enter a tile which is already full,

it will accumulate in the leader and may build up to a head of fifteen or more feet. The resulting pressure inside the tile will force water out of the joints and cause erosion and misalignment that may result in entire failure.

On the other hand, if tile size is ample, the swift current of gutter water will tend to carry away dirt which may work into the tile from the ground.

If dry wells are used, it is best to place them well away from the house.

Where porous fill is available, it should be used for backfill against the foundation to prevent water pockets from forming against the wall. Surface water can be kept out of it by sloping up toward the foundation, and by placing a capping of topsoil.

Porous breather pipes or a hollow tile outer wall may be carried from the tile to the surface, against the foundation. Air chilled by contact with the ground tends to flow down the drain to the outlet, and when it can be replaced by warm air pulled down from the surface the resulting circulation warms the soil and the wall, and reduces the problem of condensation inside the cellar.

A house which has been built without subdrains or with inadequate ones can often be protected by installing a deep curtain drain along the uphill slope. This may be built to cut off underground water only, or to take care of surface water as well.

If a cellar is to be built in a hole blasted out of solid rock, it is good practice to provide a sump hole, about three feet deep and square, in a corner.

If water difficulties develop, an automatic pump can be quickly installed to remove it from the cellar itself, or from the floor base where it might otherwise build up enough pressure to cause heaving and cracking.

The sump can be protected with a manhole cover when not in use. A 36 inch sewer tile open at the bottom makes an excellent lining.

This is cheap insurance against the possibility of needing an expensive and damaging ditch blasting operation, or an elaborate waterproofing job.

Waterproofing. If there is no downhill point or storm water pipe to which subsurface water can be drained, and location and soil type indicate the probability of ground water, the cellar should be waterproofed. This can be done more thoroughly and economically during construction than afterward.

A minimum treatment which should be given to the underground part of any house wall, except possibly in arid regions, is a coat of waterproof paint. This will seldom suffice to keep out water that is trying to force its way in, but will cut off the capillary water which is a large factor in wall dampness. Mixing waterproofing into the surface coat of the floor is also helpful.

A complete waterproofing job starts when the footing is complete, and before the walls are built. A concrete sub-floor, perhaps an inch thick, is laid and smoothed off flush with the tops of the footings. When this has set, three or four ply membrane roofing, consisting of alternate layers of roofing mastic and tar paper, or of similar materials, is laid over the whole floor area, so that it projects beyond the footing on all sides. The walls are then built of poured concrete or blocks, and membrane roofing tied in with the projecting ends of the floor covering and carried up the walls to grade line.

Water exerts considerable pressure so that larger than standard blocks should be used in the lower part of the wall, and they should be filled with cement and reinforced as well. At grade line a transition to smaller blocks may be made with the step on the outside. The waterproofing

membrane is curved in on this step, and caught under a stucco coat which goes up to the sill line. Any pipes going through the wall are surrounded by flashing.

Water pressure is even more critical under the floor. A reinforced concrete slab is poured over the waterproofing, at least four inches thick, and a surface smoothing layer of one inch may be added. Water standing up to five feet above the floor level on the outside may require a seven inch slab, plus topping. The thickness required is somewhat affected by the span between walls, or between weight-bearing partitions or columns. It is essential that the waterproofing extend under the chimney, and its weight is an effective hold-down for the slab in its immediate area.

Another method is to pour a one piece reinforced concrete floor and walls with waterproofing compound added to the entire mix. This may or may not be placed over membrane waterproofing on the floor area, but does not require that the membrane be extended up the sides. The whole job should be done at one time as leaks may develop at joints between pours made on successive days.

A floor and a foundation constructed in either manner should be permanently waterproofed, regardless of water conditions outside them. There is even some danger that if a house is not built on it, it might be floated out of the ground in a flood.

A cellar usually has an inside drainage system to take care of leaks, condensation, overflowed or broken plumbing, and such. This may open into the outlet of the outside subdrain, a storm water drain, or be caught in a sump which is emptied by an automatic pump.

Any outlet to either a tile system or a storm drain should have a check valve or a screw or clamp cap which can be used to prevent water from backing through it into the cellar.

Waterproofing a finished cellar involves multiple coats of waterproofing material on the inside of the walls, and laying membrane roofing on the floor and pouring a new slab on top of it. If there is not enough room for this, the old floor has to be broken up. The furnace should be treated in the same way as the walls, and any inside passages below the danger level thoroughly sealed off.

Condensation. Before undertaking any considerable expense to stop leaks into a cellar, it should be found out definitely whether they exist. Condensation may make substantial amounts of water appear on walls and floor. If the trouble occurs in hot weather, it is probably condensation; if in the wet season or during heavy storms, it is most likely leakage. If a piece of cardboard is secured against a suspected spot, it will get wet on the wall side if it is leakage, and on the room side if it is condensation.

Condensation may be checked by coating the wall with cement plaster or some other coarse absorbent material, or by running an electric dehumidifier in the room.

CHAPTER SIX

PONDS

The discussion in this chapter will be limited to ponds varying from a few square yards to a few hundred acres in area, which may be built according to the judgment of the landowner or the contractor, rather than according to detailed specifications.

Such ponds may serve as small reservoirs for domestic and industrial use, or to provide water for fire fighting, for animals, and for fishing and other recreation. They may also be useful in swamp reclamation, ground water replenishment, and flood control.

They may be made by damming streams, digging holes for streams to fill, digging below the water table, or by combinations of these techniques. Dry hollows may sometimes be converted into ponds by diverting streams, tapping springs, or lifting underground water by means of windmills or other pumps.

SWAMP RECLAMATION

Soil Conditions. Swamps which are wet all year are logical places to dig ponds. The spoil taken out of the excavation can be used to build up the area around it so that the section worked is changed from a bog into open water and dry land.

Swamps commonly have a top layer of soft peat or muck soil, which may be of any thickness from a few inches to a hundred feet or more. This organic material is easy to dig but provides very treacherous support for machinery. Below the muck, any type of soil or rock may be found.

The reader is referred to Chapter 3 for techniques in handling the mud that is one of the usual problems of swamp work. The dragline is the best machine for swamp digging and mud handling.

Mud may be reduced or eliminated by working in a dry season, by diverting, draining, or pumping out the water before or during the work, or drying up the area by sump or well point pumping. These techniques are discussed below and in Chapter 5.

It is very advantageous to get rid of as much water as is reasonably possible. Water prevents the operator from seeing the bottom he is cutting, with resultant wasted passes and gouging. It reduces the digging effectiveness of the bucket so that some soils which can easily be dug when dry cannot be penetrated when under a foot or two of water. Even with skillful operation, water will mix with soil in the bucket, making sloppy spoil piles that reduce the amount of digging at a stand, and which sometimes will flow back into the excavation or cut off the shovel's exit.

Digging Plan. Figure 6-1 shows a general plan for digging a pond in a swamp and using the spoil to build up the unexcavated parts. A drainage hole is dug at the downstream end, and the water level lowered by a ditch drain or by pumping. A sill may be placed at the entrance to the

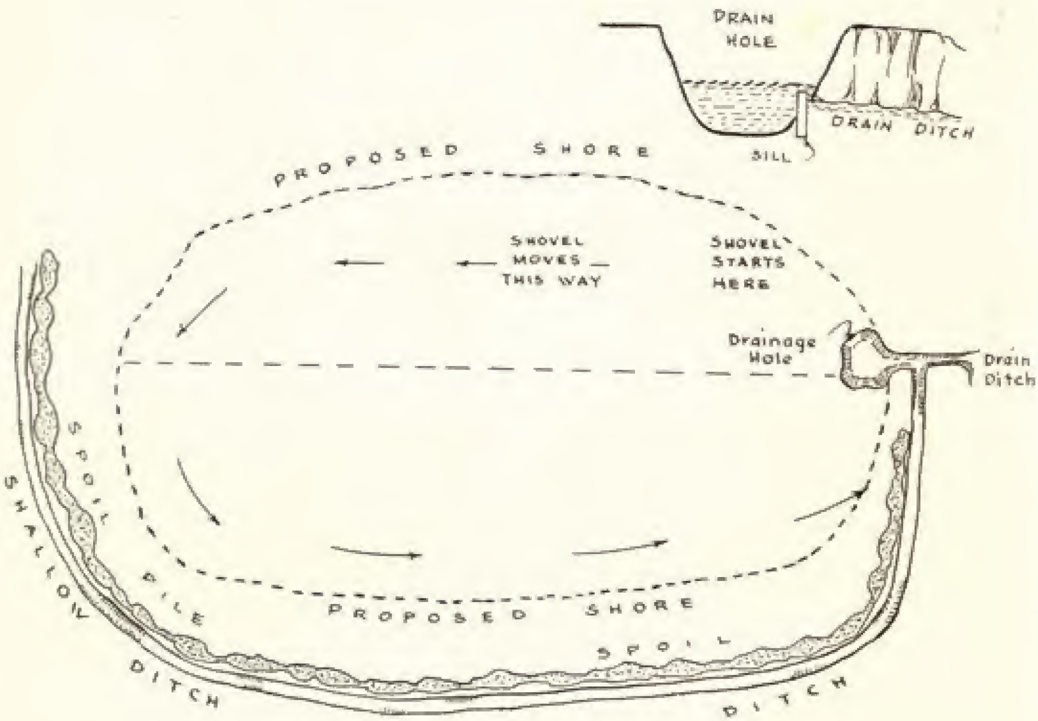


Fig. 6-1. Digging plan for swamp pond

ditch or the sump hole to hold water back a few inches above the floor of the proposed pond.

If the swamp is fairly dry, and the digging is fast and continuous, the removal of water may be unnecessary as the expanding excavation may keep the water at a low enough level so that it will not cause trouble. Surface water may be diverted around the excavation by shallow ditches or dikes as shown, or be allowed to flow into the hole.

If no obstructions prevent, the pond is dug from the center toward both sides, with the dragline walking along the longest dimension, which is usually parallel with the direction of water flow, as in Figures 6-1 and 6-2. The machine keeps back far enough from the center line so that it can reach it with an easy cast. It usually works on platforms or other artificial supports, but if the swamp has been drained enough in advance to be firm, or has gravel soil, or a heavy mat of bushes, these may not be necessary.

The bottom is kept on grade by digging just enough to let the water back over it. If there is not enough water to cover the enlarging bottom, the grade may be checked in the same manner as in a cellar excavation.

The length of a pond of this type can be increased indefinitely without change of method. The width, however, is limited by the reach of the dragline and the depth of the hole. The reach determines the width of the strip in which it can dig and pile, and the height of the piles; the depth governs the part of that width which must be reserved for piling spoil.

If a wider pond is required than the machine can dig in one round trip, as illustrated, it must go behind the piles, drag or swing them away from the excavation, and then widen the hole.

Size and Depth. Calculation of the size

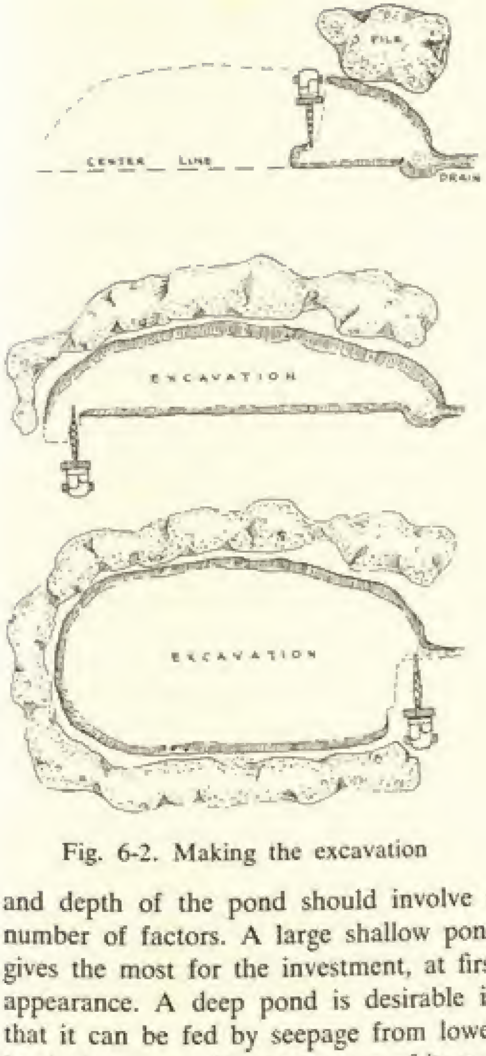


Fig. 6-2. Making the excavation

and depth of the pond should involve a number of factors. A large shallow pond gives the most for the investment, at first appearance. A deep pond is desirable in that it can be fed by seepage from lower levels, loses a smaller percentage of its water by evaporation, does not lose area by silting as readily, discourages growth of bottom weeds, and is more suitable for fishing and swimming. Against these advantages are increased cost and a possible drowning hazard.

Deep ponds may often be obtained from shallow excavations, or without excavation, by building of dams and dikes; but for the present we will consider results obtained by excavation only.

The pond should be dug to a clean bottom, if possible, and should yield enough spoil to build banks a foot or more above the water at the edge, and sloping up away from the pond for drainage. In a limited area that is to be reclaimed, an increase in water surface reduces the area of the banks and the amount of fill needed for them. Fewer yards need be moved for a large shallow pond than a small deep one of the same capacity; although a larger proportion of the yardage may have to be moved more than once.

Cut and Pile Relationships. Figures 6-3 and 6-4 show some of the relationships between the cut and the spoil piles. The diagrams show a machine with a 40′ boom, digging beside and behind itself, and have been simplified by assuming a constant dumping height of twelve feet; an increase in volume of the spoil of 20 percent, nearly vertical slopes in the cuts, a one on one-and-a-half slope on the piles, and soft soil permitting deep digging. Figures on the

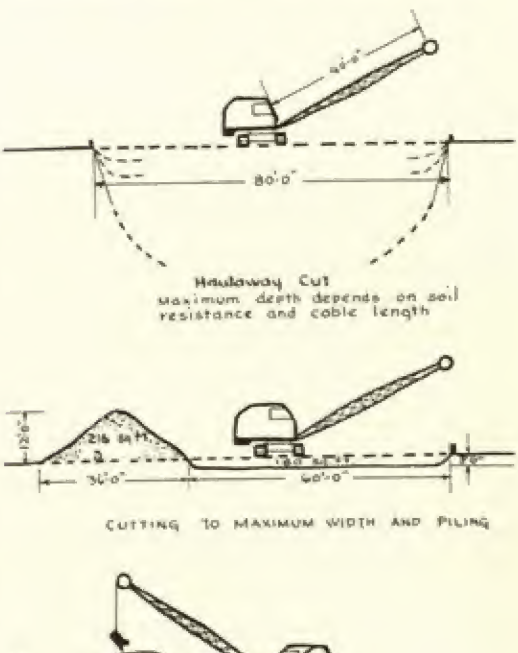


Fig. 6-3. Dragline cuts

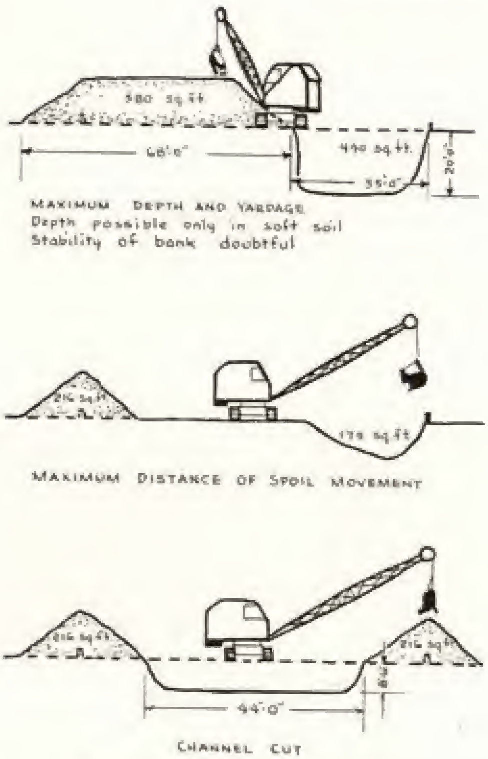


Fig. 6-4. More dragline cuts

piles show cross section areas. Muddy conditions cause piles to be lower and wider, reducing the width of cuts.

The dumping height increases with higher boom angles, an advantage partly offset by a shorter dumping reach. A low boom is preferable for deep digging and to obtain a good digging reach without casting the bucket. Extra pile height may be obtained by raising the boom to put a top on it, but keeping it low for the bulk of the digging. A dragline with a live boom can lower it for digging, and raise it for dumping during the swing; but the extra power needed limits this to occasional use.

If the shovel is tipped by having the track toward the digging lower than the other, the boom will be low for digging and high for dumping. This is a dangerous practice on any but the firmest soils, and as it shifts the center of gravity downhill so that lifting capacity is reduced, and the low track will tend to sink more than the other. The combined effects might cause the machine to overturn.

The swell and the slope of the soil piles indicated in the diagrams might or might not be applicable to a particular job. The regular cross section shown will be found only in sand or other free flowing, non-saturated material.

The volume of the piles may be increased by moving the dragline behind them, and pulling them or swinging them back periodically. This extends the pile toward the rear and leaves room for more on top. This is practical if ground conditions permit work without platforms, but otherwise takes too much walking time. A second dragline working behind the windrow and swinging it back makes a very effective combination.

If the excavation is narrow and shallow, and the banks narrow, a long boom dragline may excavate without building a pile by placing each bucket load in its final position.

Double Cuts. If the width of the pond is to be greater than can be dug in the two cuts described, the dragline may make additional cuts, first removing the spoil windrow, then the ground under it.

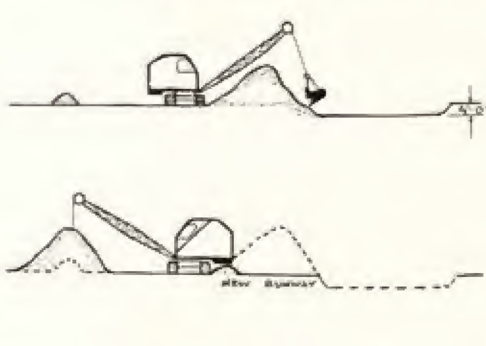


Fig. 6-5. Double handling

The windrow is usually moved by standing behind it and digging with a short dump cable, so that the loaded bucket can be picked up without pulling in. It is swung to dump as far back as possible, and a level runway made to permit the dragline to work along the rim of the original cut, as in Figure 6-5.

If the pile is too large to allow the bucket to reach across it, part of it may be dug away, as in Figure 6-6, and the balance removed at the same time that fresh ground is dug.

The runway is normally made at the original grade, as vegetation or drying makes it more firm than the soil underneath. However, if the soil is hard to cut, the runway may be lowered to improve digging efficiency. If digging is easy, and the dug soil dry and firm enough to support the shovel, the ramp may be made higher, as in Figure 6-7, to increase the dumping height. The cross section of a pile increases about in proportion to the square

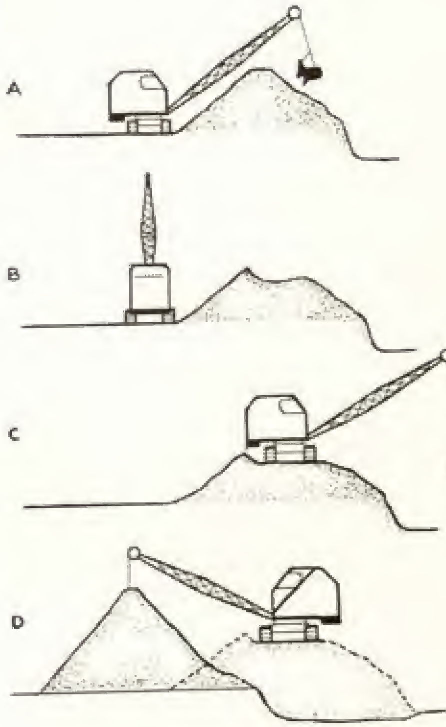


Fig. 6-7. Working from top of pile

of the height, so the advantage gained is important. The freshly moved dirt is left higher than the undisturbed part of the pile, as it may settle seriously under the dragline. If possible, the machine should be kept on the consolidated part.

If the pile has a wide top, it may simply be leveled by a bulldozer, or by the dragline raking and patting it as it travels along it. However, it should be remembered that the tops of piles are treacherous at best, the machine should be kept back from the edges, and the pile watched carefully for evidences of caving, particularly toward the digging.

As shown in the illustration, a dragline working on top of a pile is able to not only move the whole pile back but to dig the ground under it in one operation.

For even wider ponds, additional cuts may be made. Each additional slice involves moving all the material which has

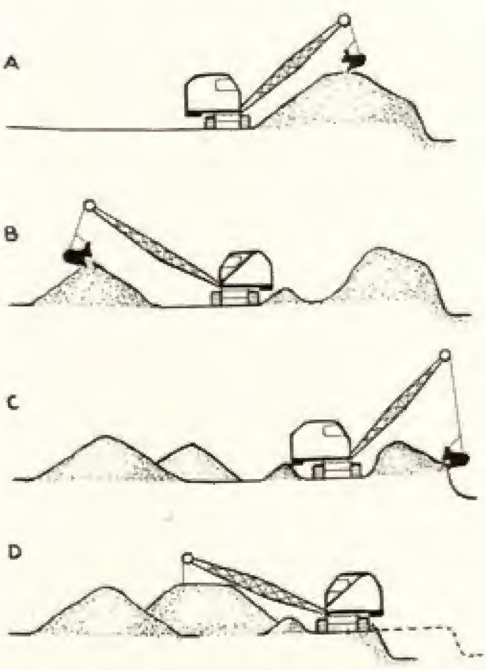


Fig. 6-6. Working back a heavy pile

been dug, with increasingly complicated patterns, and expense mounts rapidly. Usually more than two cuts are made in one direction only when the operation involves cleaning off vegetation and shallow digging. In deep work, trucking the spoil or removing it with slackline excavators or conveyors, is more economical when several rehandlings with a dragline are necessary.

Trucking. A flattened windrow, such as is shown in Figure 6-7, may be used as a truck road if it is dry and substantial enough, and is connected with dry land at one end. The dragline, or a hoe, may be started at the far end and worked toward the exit. It may dig to final grade, leave a shelf for further dragline work, or it may load the dry material in the trucks and cast the wet stuff from the bottom to build up a new windrow.

Abnormal delays may be experienced in the trucking. It is usually not practical to build turnarounds or two-lane roads, so the trucks must back in the full distance from shore, and no other truck can enter until the previous one has left, thus leaving the shovel idle each time. There is also danger of trucks going too close to the edge, or encountering soft spots, so that they get stuck or overturn.

If the windrow can be connected with dry land at both ends, scrapers may be used to remove the dry upper part.

Material may be trucked away economically if the pond is to be large in proportion to the size of the shovel, so that several shovel handlings would be required; if there is insufficient space in the digging area to pile the spoil; if fill is needed elsewhere on the project, or if the spoil can be sold. Under some circumstances, the entire cost of making the pond may be repaid by the sale of the spoil.

Selling Spoil. Materials that might be sold out of a swamp include the organic earths, such as topsoil, muck, and peat (humus); and inorganic subsoils such as sand, gravel, clay, and loam. Frequently, the values of these materials are destroyed if they are mixed together, as the presence of organic matter makes subsoil undesirable or useless as a structural fill; topsoil or other organic earths are not salable if coarsely mixed with subsoil.

Swamp topsoil and mucks are generally too heavy in texture for use in lawns or gardens, but may improve greatly if left in piles for a year or two, or if mixed with sand or light loam. Nearly pure peats, however, are widely used to enrich soil, and command a fairly good market. These have a very high water content, and may shrink 50 percent or more in the pile.

If the spoil is to be used for the pond banks, or similar unloaded fills, organic and inorganic dirt is generally dug and handled together. If they are to be sold, the topsoil should be stripped and piled to the side, and the subsoil dug afterward in a separate series of operations. As the surface of the subsoil is often below water level, adequate drainage or a dependable pumping system should be provided before putting the shovel on it. The diagrams in Figure 6-8 show a succession of operations in selective digging.

Separation of materials in several layers may be very complex. Examples are digging gravel interrupted by seams of unwanted clay, digging clay seams lying between sandy layers, the decision as to what is desirable being a matter of local demand.

If the dragline is large, or has a long boom in proportion to the area to be dug, these layers may be removed and piled separately, or they may be stripped back separately in the same manner as topsoil. Often, however, a better solution is to truck away the least bulky or sometimes the most valuable of the materials during the digging. Trucking may be possible only during a short period late in the dry season, after a protracted period of artificial dry-

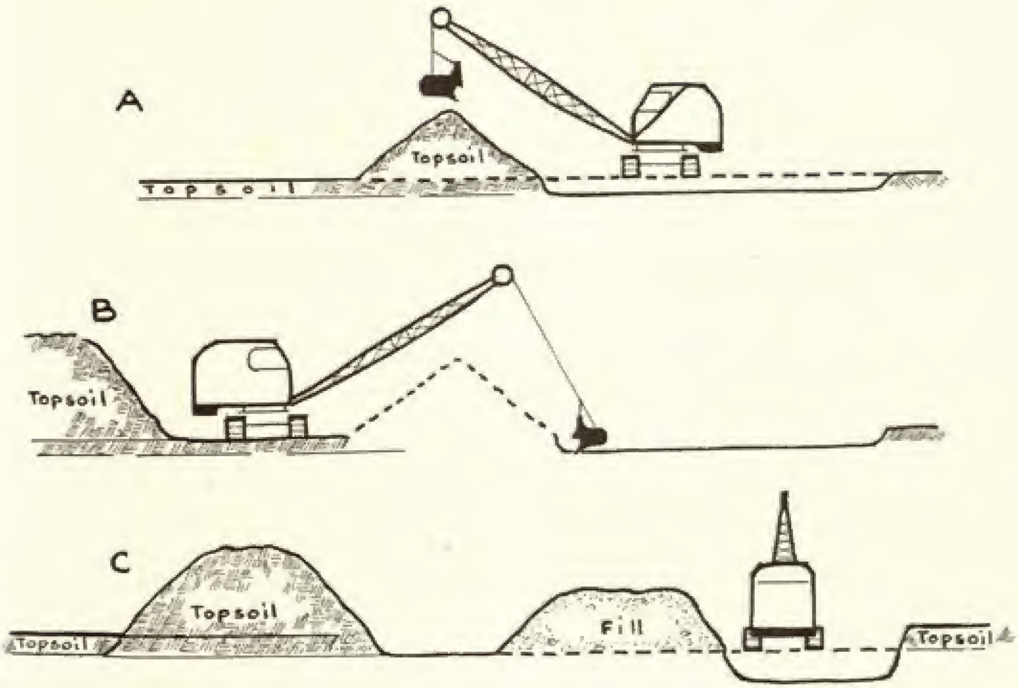


Fig. 6-8. Selective digging

ing by drainage or pumping, or only after construction of fills or timber roadways.

Selective digging should be done in the dry, so that the operator can see what he is doing. It will be discussed further in connection with borrow pits in Chapter 10.

Predraining. Whenever the soil is to be trucked out, or when very sloppy conditions are found in a swamp, it is advisable to investigate the possibility of drying up the area before work starts.

Almost any spot can be dewatered, at a price, by diversion of any streams or other surface inflow, and well point pumping.

Sump pumping may be more economical when surface water can be diverted, and when underground reservoirs are small, or when relatively impervious soils cause ground water movement to be slow. The soil must be fairly stable.

The sump is a deep hole with a bottom below the proposed digging. One side should be sloped gradually or terraced so that a pump can be set up wherever desired. Outlet hose, or a flume or ditch, must be provided to lead the water out of the area being dried.

For best results, pumping should be started around the beginning of the dry season. If the swamp is underlain by porous gravel or sand, most of the water can be removed from small basins in a few days, and additional pumping will be required only occasionally. In large basins, continuous pumping might be needed during the job. If the soil is tight, less water will be removed at first, and seepage into the hole will be reduced very gradually.

This operation should cause the swamp to dry up, so that difficulties with mud will be reduced or eliminated. However, the effect may be largely lost if heavy rains saturate it again before work is started.

Both the speed and effectiveness of sump pumping can be greatly increased by drainage ditches leading into the sump. A

horseshoe-shaped trench enclosing the working area, but leaving an undisturbed space for entrance of machinery, is a convenient layout. Such a trench may involve piling hundreds or thousands of yards of spoil, but should be a good investment if it allows dry digging for the bulk of the project.

Peat will burn except when saturated with water, and a peat deposit drained as suggested might be entirely lost by fire. If this material had no value, this might be the quickest way of removing it. The fire would also loosen any stumps, and if deep, might consume them.

A peat fire might produce tremendous quantities of black or bad smelling smoke, burn for a long time, and be difficult to prevent from spreading. Such a fire should be started only after consultation with local fire and police officials.

DRAGLINE SIZE

Choosing the right size dragline for pond dredging in swamps involves consideration of a number of factors. Small machines are more easily supported on soft ground, are easier to salvage if they get in trouble, can work in restricted quarters, and usually have a faster digging cycle. However, they must handle material more often to move it the same distance; cannot dig as deep or pile as high or penetrate hard material or take out stumps as effectively as larger machines, and cost more for each yard of digging.

Small draglines may be equipped with long booms to match the reach of large machines, but this reduces their speed and may interfere with stability. Additional counterweight is advisable, and the inertia of this and the reduced leverage on the bucket load causes it to take more time to start and stop each swing, increasing the cycle time by one to five percent for each foot of boom added. If the swing clutches or engine power are barely adequate to manage a standard boom, loss of time through excessive slipping or lugging down will be much greater than with a high powered machine of the same rated capacity.

Undersize buckets are often used with extra long booms. These reduce the tendency to tip and speed up the cycle somewhat, but reduce the payload and the ability to penetrate hard soil.

Digging Cycles. A three quarter yard shovel with a forty-foot boom digging at the end of its reach, and swinging 180° to dump, can move the material seventy or more feet at each handling and complete two to three digging cycles a minute. The same machine, in digging up its own track, may move the dirt only ten to twenty feet at the rate of three to four buckets a minute. The average distance the soil is moved may be found by measuring from the middle of the cut to the middle of the pile.

If the spoil is to be moved back through several handlings by the dragline, the long move is desirable; but if it is being stockpiled, the short quick cycle is best. Most digging patterns include both long and short swings to get maximum work out of minimum walking.

If the ground is firm enough to allow the dragline to work without supports, and the spoil must be handled several times, it may be advantageous to make only the far part of the first cut, as in the "maximum distance" diagram in Figure 6-4, after which the dragline moves behind the pile and moves it back through another 180° swing. It then works from the spot where the first windrow had been, widening the cut somewhat, and building another pile. These piles may be moved back again to leave space for further digging.

This requires much more moving to do the same amount of digging than when the dragline digs as much as it can. It may also be found that even if the ground sup-

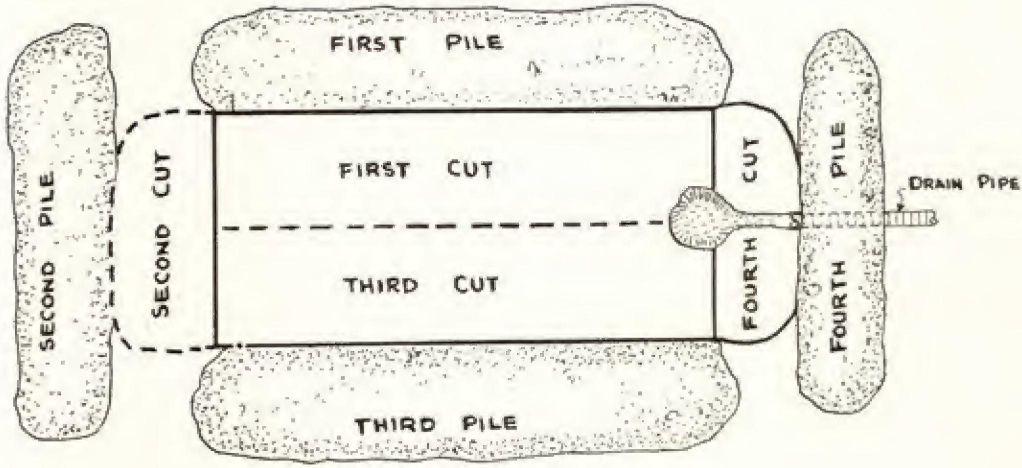


Fig. 6-9. Straight end cuts

ports the shovel before work starts, piling and removing such amounts of mud may soften it so that platforms must be used.

It is sometimes necessary to make breaks in spoil windrows to allow areas behind them to drain. These may be left open during the piling, but this is difficult when the windrow is as large as the shovel can build. They may also be made after piling by moving the machine behind the windrow and cutting a slot.

Building Up Ends. If fill is needed at the upper and lower ends of the pond, the dragline may dig and pile in a curve as it rounds the ends, as in Figure 6-2. Another method is to make straight cuts across the ends, as in Figure 6-9. Such work at the outlet will block the drainage ditch, or interfere with pumping, so that it should be the last spot to be dug.

Drainage may be maintained by laying pipe in the ditch before covering it. If the spoil is to be spread after the first cut, such pipe may be left permanently, being fitted with a cap or valve so that it may be blocked to fill the pond, or opened to drain it. If two or more handlings of the spoil are necessary, temporary pipe must be placed and then lifted as the digging progresses, for which purpose corrugated steel is most satisfactory because of ease of handling and resistance to rough treatment.

Islands. Both the quantity and difficulty of digging can often be greatly reduced by building islands. In cases where a shallow cut is made, and the balance of the depth obtained by building a dam, most of the spoil can be disposed of in islands. If cutting is deep, some spoil may still be piled on them and their bases do not have to be excavated.

Islands may be built at spots most convenient for disposal of spoil, or according to other requirements. A finished height of two or three feet above water is desirable. In humus, piles six feet or more above water level may be needed because of loss through shrinkage, smoothing the top, and slumping under water.

Grading should be done by the dragline immediately after piling, or at least before the pond is filled.

It is desirable to have some uninterrupted stretches of water in a pond. These may sometimes be located at low spots, where the digging is not deep enough to make rehandling burdensome, and the islands are located where disposal of material is more of a problem.

Under some circumstances, however, the open water will be located in formerly high ground, where the spoil can be trucked

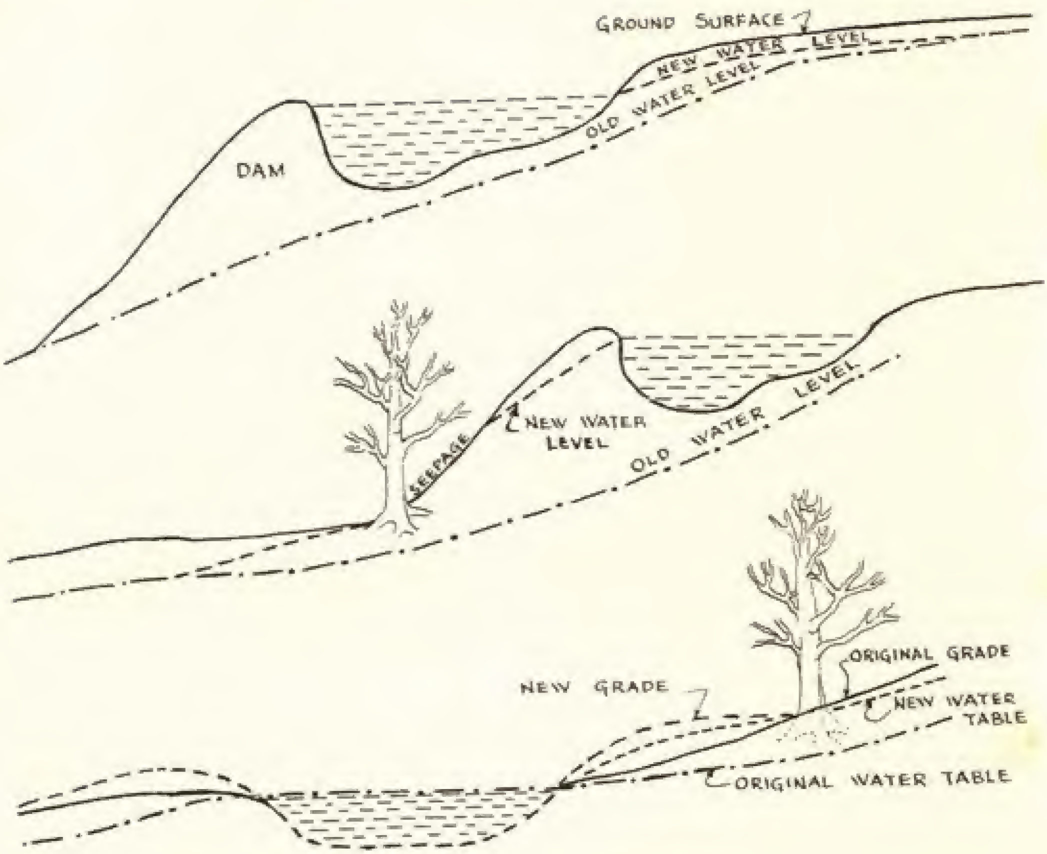


Fig. 6-10. Changes in level of ground water

away and the islands built in the soft areas.

Trees. Pond sites are usually not as open and regular as the examples discussed above. One of the commonest obstacles in the way of systematic work is a tree, or a group of trees. One tree can cause an increase in dragline time of three or four hundred percent for the digging in its immediate neighborhood, and two trees may make the digging impossible without the use of trucks.

This is one reason why most pond diggers recommend making a clean sweep of all trees within boom reach of the excavation area. Another factor is that if the water level is raised by construction of a dam, or if fill is placed around a tree, even with protection for the trunk, it is liable to die, and large and old trees are particularly sensitive to any such changes around its roots.

Pond construction may cause injury or death to trees at some distance from the work. If a dam is built, the water level may be raised not only at the pond edge but to a decreasing amount for hundreds of feet back. Water level may be raised even when a dam is not built by ground water backing up behind impermeable fill from the pond, or as a result of raising the grade of the banks. In addition, seepage may drown out trees below a dam. See Figure 6-10.

Moderate lowering of the water table will only occasionally damage trees. Such lowering may be caused by digging into and draining a water bearing layer formerly having an outlet on higher ground,

or, in the case of a pond without a dam, by digging back into a bank.

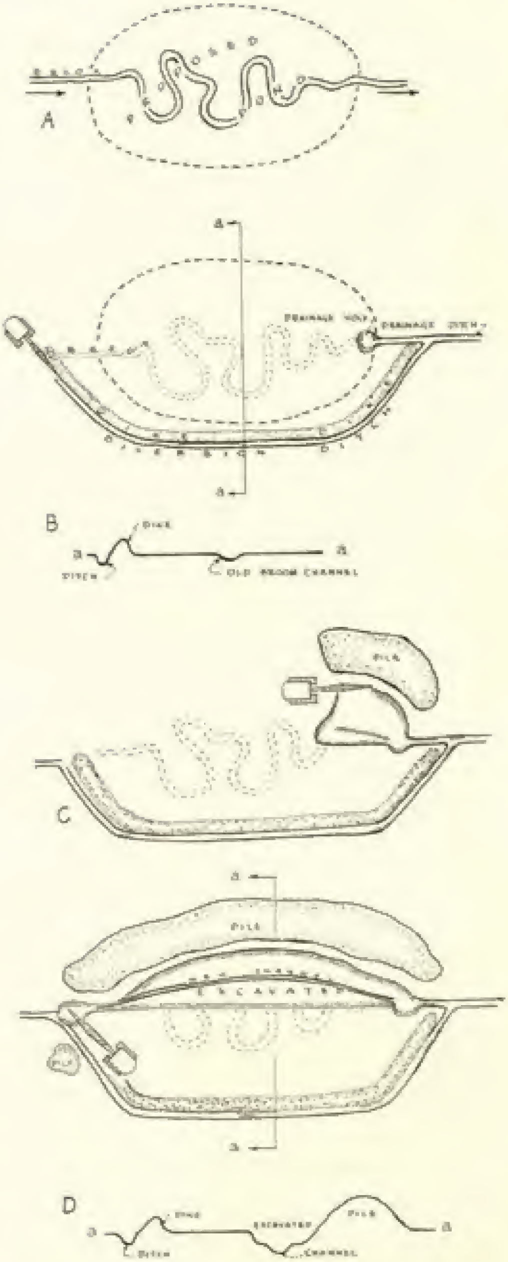


Fig. 6-11. Digging in stream bed—gravity drainage

Methods of protecting trees during construction and from the effects of changes in ground and water level will be discussed in the chapter on landscaping.

Removal of small or worthless trees near the pond, and of trees which would shade a beach or float, is desirable from landscaping and recreational standpoints. A strip of grass on the pond edge that can be trimmed will make it easier to keep the shoreline free of bushes and water weeds.

However, none of these factors justify an indiscriminate destruction of trees in the pond area. A tree may be a landscape feature of as much value as the pond, and the cost of digging around rather than through it may be only a small fraction of the entire cost of the project. Also, the cost of cutting and removing a large tree and disposing of the stump, may be greater than the cost of operating the shovel for an extra day.

It is a good plan to consult a local tree expert, informing him of the scope of the excavation, the changes in water level, and the height of any fill to be placed near the tree, to get his opinion as to its chances of survival. This information may be given to the owner with an estimate for the job both with and without removing the tree for his decision.

Rock. Ledge rock and boulders cause less difficulty as they interfere only with the digging, not with the swinging. They may often be advantageously used for shoreline or islands, as a rock slope is usually more attractive than a mud or grass bank.

Rock to be blasted must be cleaned off and should be above water during the work if possible. Standard blasting techniques are used.

Bank Preservation. If the pond site includes a dry bank of suitable height, it may be advisable to leave it as one edge of the pond, digging away from it as if it were the centerline in Figure 6-1 for the first cut, and disposing of all spoil on other edges. This technique can also be used to avoid tangling with trees or landscaped areas. If the pond is wide and without truck access, saving the bank may be too costly.

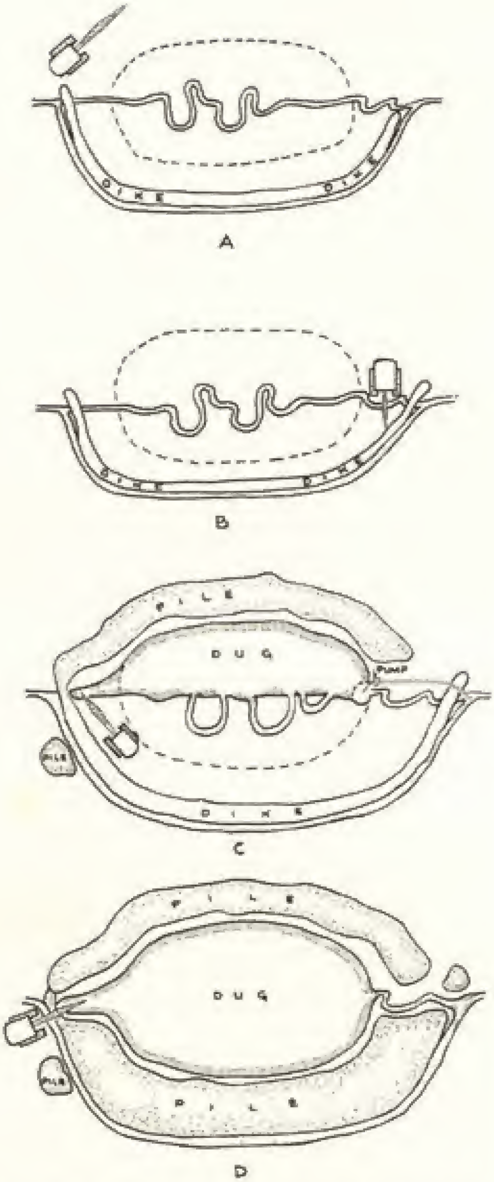


Fig. 6-12. Digging in streambed and pumping seepage

STREAM CONTROL

Digging Pattern. If a pond is to be excavated in the valley of a flowing stream, special precautions should be taken.

The diagrams in Figure 6-11 show procedures in excavating a pond similar to that in Figures 6-1 and 6-2, except that a brook runs through the center of the swamp.

A diversion ditch deep and wide enough to contain the brook is dug, starting downstream at a point lower than the proposed pond bottom, where it meets a ditch from a drainage hole, somewhat deeper than that described earlier. The diversion ditch is continued back to a meeting with the brook on the upstream side of the job. Spoil is piled on the pond side of the ditch to form a dike and to dam the original channel.

The dragline will have to walk across the brook. The banks may be dug away and platforms laid on them or in the water, or the stream may be partly filled with saplings or long logs to permit a crossing.

After diverting the water, one side of the pond is dug. A channel is cut below grade, midway between the center and side lines. At the upper end, the shovel cuts a gradual ramp up from the channel bottom, usually after crossing the dry stream bed. This ramp should be covered with a brush mat weighted with rocks, or logs or planks should be placed crosswise in the bottom to avoid excessive erosion when the dike is cut and water permitted to flow down it. Sometimes a hole is dug below grade at the foot of the incline to trap most of the dirt washed down, and the protections are omitted. The water should now follow the channel in the pond bottom, and flow over the sill into the drainage ditch, keeping away from the centerline where further digging is to be done.

If it is not practical to carry the diversion ditch to a point below the pond floor level, the pattern in Figure 6-12 may be followed. The diversion ditch is dug far enough back as to be behind the spoil pile. After the stream has been turned into it, the lower end of the stream channel is blocked off to prevent water from following it back into the excavation. A drainage hole and sump is dug, and excess water pumped into the stream below the block.

When the digging is finished, this block is removed and the dikes cut. The stream will now flow into the pond, fill it, and overflow into its old channel. Streambed erosion can be reduced by allowing the pond to fill by seepage or by controlled flow through a pipe or siphon before cutting through.

Still another method is to straighten out the stream channel so that it lies on one side of the centerline. The other side is dug and the pile extended well across the stream at the upper end, forcing it to find its way behind the pile and back to the stream below the pond.

Temporary Stream Diversion. It is sometimes possible to put a temporary dam across the stream well above the work area, and to divert it across a low ridge into another valley, or into a trench, flume, or pipe running along a hill slope in the same valley. A large pump may be used to raise the water into such diversions.

Before arranging to pump out a stream, or building a flume or pipe line to carry it, its volume of flow should be measured. This may be roughly done by placing a rectangular wood trough or flume 15 to 20 feet long in the stream bed, and packing around the upper end with mud so that all the water will enter it. Chips of wood may be dropped at the upper end, and the time they take to drift through checked with a stopwatch. Mud can be dropped in the water to find if the bottom or sides have a perceptibly slower current than the top.

The flow in cubic feet per second may be found by multiplying the depth of the water in feet or fractions of feet, by the inside width of the flume, and multiplying the product by the distance the wood chip traveled in one second.

If the stream has a fairly regular channel, the cross section area of the water in it may be calculated, and the speed of flow measured in the same manner.

Most streams are subject to considerable and sudden changes in volume, and pumps used should have extra capacity, unless it is possible to abandon the job during high water and return to it when the flow is reduced to a volume that the pumps can handle. Diversion channels, pipes, dikes, and dams should also be built to withstand high water.

Digging in Streams. If the stream cannot be diverted, the digging of each strip should start at the upstream end and move downstream. The dirt loosened but not picked up by the bucket will be washed downstream in considerable quantities which might entirely silt up any downstream excavation.

Riparian Rights. Laws relative to stream use and pond construction vary in different states and localities. Generally, owners of land on a stream below the job must give their permission before the stream can be diverted, even temporarily. They also can collect damages if mud from the excavation work chokes the stream, or is washed onto their property. Excavation permits are often required. It is well to have the law and the neighbors consulted before starting any important pond project.

Permanent Stream Diversion. A pond usually is kept in the best condition and appearance if a strong flow of water goes through it. However, if the pond is to be managed for the production of fish; or if the stream is likely to fill the pond with silt, it may be advisable to make a channel for the stream around the pond, keeping only a controlled flow from it into the pond through a pipe or ditch.

It is difficult to overestimate the power and destructiveness of even a small stream in flood, and it is at floodtime that the greatest damage can be done to a pond. It is therefore important to take every precaution to prevent the stream from breaking out of its prepared channel.

The diversion should start, if possible, in a stream section headed in the right direc-

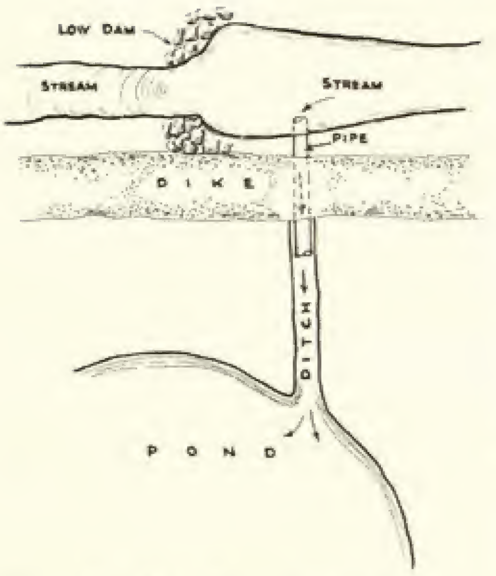


Fig. 6-13. Controlled inflow

tion; and often should be reinforced with heavy rocks or posts driven into the base of the bank on the outside of the curve. If the turn must be in the artificial channel, it should be a gradual one, protected with rocks, posts, or a well anchored timber bulkhead. A high earth dike should be built between the stream and the pond, planted with sod, bushes, or trees.

Figure 6-13 shows a safe arrangement. A low dam of concrete, masonry, or fitted rocks is placed across the stream to raise its level a foot or so. A pipe leading to the pond is placed below this water level, and a dike of earth or concrete placed over the pipe.

Water in excess of that which will pass through the pipe will flow over the dam into the channel. The pipe may open into a ditch, or continue into the pond. Flow may be reduced by means of a gate valve, or by partially obstructing it with a board, or by placing stones at its mouth.

SHORES

Spreading Piles. After a pond is dug, it is usually surrounded by spoil piles whose size and arrangement depend on the reach of the machine, the digging plan, the shape of the pond, and obstacles to digging or walking. These piles may be left to dry for ultimate sale or removal, but more often are knocked down and graded into banks and slopes. This can be done immediately, but if time is available and considerable yardage is involved, they may be left to dry and shrink. Light soils and some heavy ones should become firm enough so that the shovel can work without platforms, saving time and work. Peats and mucks are less likely to become firm, but lose substantially in bulk and weight.

The dragline is the preferred tool for spreading such piles. A bulldozer can be used if they are dry, and is frequently used for finishing after the dragline has knocked them down.

A dragline spreads piles by a combination of dragging down with lifting and swinging. First the machine approaches the pile closely and digs off the top. Each time the bucket is filled it is pulled closer to the shovel than necessary, sliding several times its capacity ahead of it. It is then lifted, swung, and dumped in a low spot, and the process repeated until the dirt piles against the tracks.

The shovel is then backed a few feet, and the digging and dragging continued, cutting to somewhere near final grade. The shovel continues to back and dig until the pile is exhausted, when it pulls down the lip in front of it, and walks up on the freshly graded area to work on the portion of the pile that was originally beyond its reach.

In Figure 6-14 the pile is shown to be on the edge of the pond excavation. The dragline digs this shore to its final slope, widening the pond in the process. It is good procedure to cut banks back to a slope which will be stable under water, as it reduces the accumulation of soft mud at the edge of the bottom from parts of the bank sliding and falling in.

If the spoil is in windrows, the shovel may be walked parallel to the pile, digging and pulling it down until it starts to fall against the tracks, then moving on to wreck another section, continuing until the end is reached. It then comes back, parallel with the windrow but further back, digging and dragging in the same manner. The ridge pulled against the tracks can be dug and spread behind the shovel. If the windrow is small, one trip may be sufficient.

Grading. It is sometimes possible to do the final grading while spreading the piles, but more often it is necessary to distribute them roughly to get an idea of the amount of material available, after which the area, or parts of it, are gone over for a light regrading. The finishing is done by raking and patting with the bucket.

There is probably no type of dragline work in which a skillful operator is as valuable as for spreading piles and grading banks. A long boom helps him considerably.

Unless the operator is an expert, a better

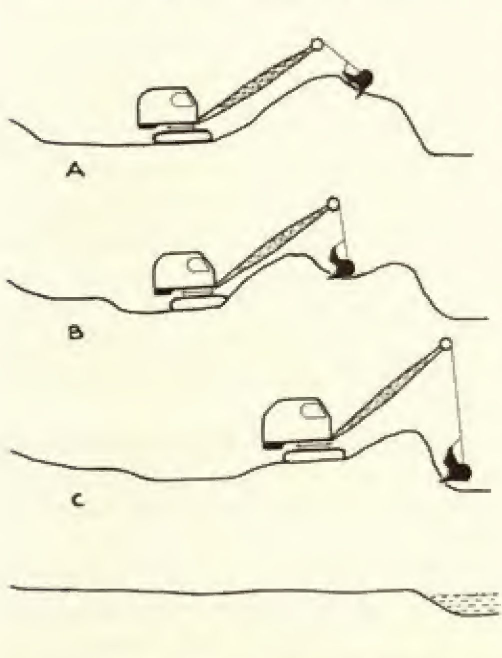


Fig. 6-14. Leveling piles with dragline

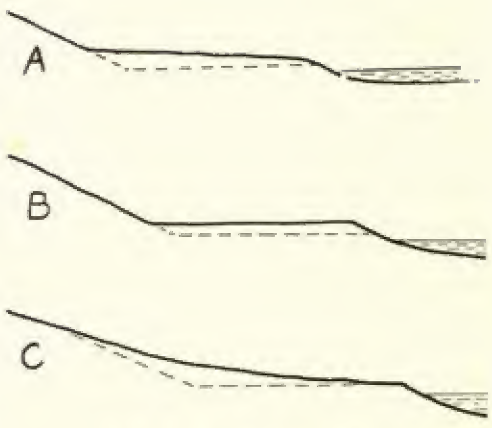


Fig. 6-15. Shore profiles

result will be obtained by finishing with a bulldozer or a grader, if the soil will support them. Also, it may be economical to make a quick rough grade with the dragline, and release it for other work while another machine finishes up.

When grading is complete, the area is usually disked and planted. Most peat soils need some time to drain, with the addition of lime, before they can support ordinary field vegetation. Testing outfits may be purchased at garden supply stores which may show the cause of trouble if things do not grow well.

Shore Drainage. The grades of the above water parts of pond banks are affected by disposal of material, securing proper drainage, the nature of the surrounding area, and the personal preference of the person in charge. Three main types may be distinguished and are shown in Figure 6-15. The shore may be low and an even slope carried up higher ground, as in (A), or the banks may be high and topped by an almost flat terrace, as in (B). A low shore and a concave slope, as in (C), is attractive and reduces the danger of water pockets at the junction of the fill and the original grade, but may stay too wet near the pond.

A difficult drainage and landscaping problem is presented by a swamp sloping

gently up away from the center, changing gradually from wet swamp to dry meadow. Even when tapered to a thin edge, the fill is liable to create a wet spot where it meets the meadow, either because a dike is formed holding surface water on the lowest part of the meadow, or because the whole fill is relatively impervious to water, stopping underground seepage and causing it to overflow at the top edge of the fill.

If possible, the excavation should yield a sufficient volume of spoil to carry it far enough into the meadow to be well above pond level. When sufficiently dried, the lower part of the meadow and the upper part of the fill should be deeply plowed and disked, then blended together with a bulldozer or grader.

If wet spots still appear, they can usually be relieved by mole drainage starting at the pond shore. If this is ineffective, tile or rubble drains may be required.

Shore Erosion. Freshly built banks will wash and gully badly in heavy rains unless protected. Drainage coming from undisturbed slopes across the fill is particularly destructive. This can often be diverted by shallow ditches made with a plow or by hand. These may be leveled after the banks are anchored by a firm sod.

Disking hay or straw into the surface of the ground increases its resistance to erosion and may supply ample grass and weed seeds. Unless applied with a nitrogen fertilizer, it may delay the growth of vegetation by temporarily absorbing this element from the soil. Such mixing in or scattering hay on the surface is helpful in holding soil that has been graded too late in the year for planting.

Beaches. If a pond is to be used for swimming, a beach is very desirable. It may also be of use for wading, picnicking, and getting small boats in and out of the water.

A maximum exposure to sunlight is desirable for at least part of a beach. This is best obtained by locating it on the north or east bank, so that midday or afternoon sun, or both, comes over the water. Reflection intensifies its heat and the slope of the beach is favorable to its reception. In most localities, more swimming is done in the afternoon than in the morning.

If the beach must be located so that its sunlight comes over the land, it may be necessary to cut a number of trees to obtain exposure. If the beach is large, enough trees should be spared to give shade over some part of it, or over a lawn area adjoining it. Sometimes a tall tree that is removed may be profitably replaced with one or more smaller ones to shade a smaller area.

If the pond is being dug, or can be emptied, the beach site can be graded. A gradual underwater slope is desirable for small children and non-swimming adults. Vigorous swimmers are likely to prefer a steep underwater slope, particularly if the water is usually cold. The dry section is usually gently sloped or flat.

A beach must be protected against runoff of water from surrounding land as this will wash away the sand, spread dirt on it, or do both. A grass-covered ridge immediately behind the sanded area will serve to divert water, and may also function as a very welcome windbreak and heat-conserver.

It is desirable to have the beach subgrade a cut rather than a fill, and of firm material. If this is the case, three inches of sand might suffice for a cover for swimming purposes, but not for building of sand castles. Six inches to a foot is a safer but more expensive depth.

If part of the pond bottom is sand or fine gravel, some of it may be pushed or carried to the proper location during the excavation work.

If the subgrade is soft mud, an attempt may be made to stabilize it with clean bank gravel, pea gravel, or fine crushed rock. A layer of lawn clippings or hay placed immediately before the sand may prevent

mixing with the mud. This, of course, is not practical underwater.

An attempt should be made to extend the sand blanket to a depth of four or more feet below pond level, so that swimmers who are sensitive about walking on mud will be able to take off before they reach it.

Any clean sand that is suitable for concrete or plaster can be used for beach sand. Coarse grades are more attractive than fine, and light colors are better than dark. Where obtainable, white sand from ocean beaches or bars is most satisfactory, but it is apt to be much more expensive than pit or mason's grades. Sometimes the bulk of the beach is made with a cheap quality, and the surface dressed up periodically with a better grade.

A beach will usually require an additional two or three inches of sand after the first year or two, and occasional freshening up with smaller quantities afterward.

Fire Control. A pond is a valuable asset for fire fighting. Country fire apparatus and many city units have suction pumps so that they can get their water supply from ponds as easily as from hydrants. Even a small pond provides enough water to supply hoses for a considerable time. Many fire crews carry enough hose to utilize water a half mile or more from the blaze. An accessible pond may reduce fire insurance rates substantially.

Suction lines are short, so a rock fill or other firm surface should be provided to allow equipment to get close to the water in any weather. A deep hole should be dug near the shore. A wood or masonry wall to allow the suction hose to enter the water vertically instead of sloping down a bank adds to pumping efficiency. Any shallow bars separating the pumping hole from the bulk of the pond should be ditched.

Such a deep spot also serves well as a location for a diving board and an entrance ladder.

SPECIAL PROBLEMS

Clearing. Land clearing adds materially to the cost of reclaiming swamps, sometimes being more expensive than the earth moving. Trees, and usually brush, should be removed or burned in advance of digging. Because of soft footing the cutting is usually done by hand, but tree trunks may be dragged out by tractors or winches.

Stumps. The stumps should be cut high in the area to be excavated, and very low where the spoil is to be piled. Height gives leverage which helps in digging them out, and affords a grip for chains for handling them, but makes disposal more difficult.

High stumps in the area to be filled will cause major difficulties during grading by hanging up machines, or tipping or breaking platforms, and by requiring excessive depth of fill.

When a large stump is dug, a slow process of cutting roots, overturning, and dragging out may be required. They are sometimes too heavy to pick up, and must be dragged out of the way, or cleaned and reduced by hand, or split with blasting wedges. Lighter stumps, which can be lifted, cannot ordinarily be held in a bucket and must be gripped with tongs, or chained. Stumps should not be allowed to rest partially on the ground while being swung as they will put a serious twisting strain on the boom.

Swamp stumps seldom have tap roots, and the lateral roots are very close to the surface, so that they tend to come out as rather thin sheets. These can be most conveniently picked up by a pair of tongs inserted somewhere in the root mat, and chained to the bucket. If the ground is soft, the butt of the stump may be turned down, and driven into the mud in the fill area by patting the roots with the bucket. It is sometimes possible to entirely dispose of large numbers of stumps in this manner.

If this cannot be done, and the dragline

is working alone, it may be necessary to put the stumps in the spoil pile where they cause trouble in re-handling. When the spoil is being spread, an effort should be made to rake out the stumps first and put them in the lowest spots, driving them in if possible in order to bury them. If they are too big to bury, they must be piled up to dry for eventual burning, or, more rarely, loaded in trucks and removed.

Digging in stumpy swamps is greatly simplified by the help of a crawler tractor, preferably equipped with a winch, which can stay on firm ground and pull the stumps away as the dragline digs them out. These stumps may be winched or bulldozed into low spots for burial under the spoil; scattered around to dry before piling for burning, or piled immediately by passing the winch line through a pulley held high by a tripod, or a stout tree.

The high pulley arrangement decreases the power needed to drag the stumps, but unchaining them on the pile is a messy and somewhat dangerous job. The tripod or tree is usually destroyed when the stumps are burnt.

Logging tongs are the preferred tool for gripping muddy stumps for winching. When a chain is used, notching the butt reduces the inclination to slide off.

Boulders. Large boulders also interfere with digging and are very likely to cut the drag cable if lodged in front of the tracks. It is sometimes possible to dig deep holes in which they can be buried, or to line them up along the edge of the pond where they should improve the appearance of the bank. However, they are more difficult to winch out than stumps, because of difficulty in getting a grip on them, and are an even greater nuisance in rehandling spoil. Often it is best to break them with dynamite, or air or hand tools, into pieces small enough to bury or mix with the spoil.

Hard Digging. A small dragline has great difficulty digging hard or rocky soil. It will do its best if the soil is not covered by water; if the bucket teeth are sharp; the boom held at a low angle, and the shovel footing kept as low as possible.

Occasionally a swamp floor may be of cemented gravel or decomposed rock which can be broken up with a tractor drawn ripper. Such floors, and most hardpans, can be effectively dynamited if charges can be sunk deep enough in drilled or hand dug holes. It is sometimes sufficient to blast a small area in which the dragline will be able to cut to depth, as it may be able to maintain this depth through the undisturbed material around it. If the whole bottom needs to be blasted, it will probably be cheaper to use other machines. Sometimes a single heavy blast will soften clay throughout the whole area.

Backhoe. A hoe shovel has quite effective penetration, but is hampered in pond digging by the inability to pile spoil at a distance. This limits the amount it can dig and exposes it to the danger of getting caught in slumping piles. A very good working team is a pull shovel digging the hard soil and a dragline taking it away as fast as it is dumped. Best results are obtained if they work together, but because of the exact timing required to avoid accident, it is safer for the hoe to cut as much as it can pile and move on, with the dragline following at a discreet distance behind. At the end of the strip the hoe may turn and work back, building a new pile to be removed by the dragline.

Clamshell. A clamshell with a heavy bucket has good penetration, but works quite slowly, and is at a disadvantage in sticky soils because of suction holding the bucket down. If used, it may do the digging and the casting back and spreading; or the rehandling of loosened material may be left to a dragline.

Dipper Stick. A dipper stick can break up the bottom providing drainage is adequate and dependable. The machine can

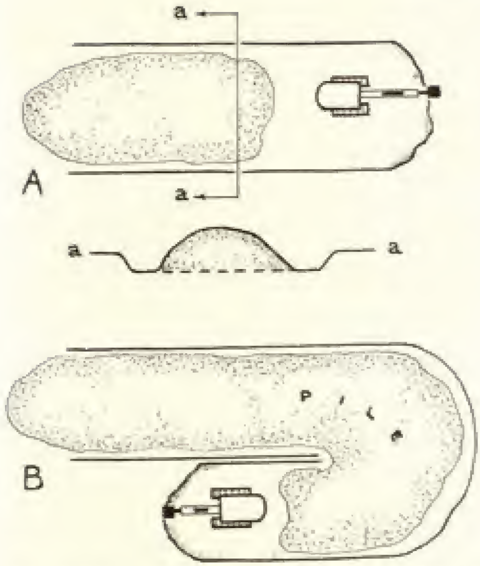


Fig. 6-16. Loosening hard bottom with a dipper shovel

operate on pontoons and ramp itself down to the required depth, and dig as wide a cut as it can reach, or is required, dumping the spoil in a ridge behind it. It may come out of the pond site elsewhere, or turn and emerge near the entrance point, as in Figure 6-16. Material broken up in this way can be easily dug by a dragline, but may be so soft as to be unsafe even on platforms, until it is well drained.

It rarely happens that a layer under a swamp is sufficiently firm to carry trucks, but in this case regular cellar digging techniques can be used.

Bulldozer digging in softer mud is done by methods described below for pond cleaning.

Water Level Determination. Pond water level depends on the height of the overflow point, whether it is a stream bed, or an artificial spillway.

The best way to decide the new water level is to lay out a grid and take elevations throughout the area. The boundaries of a pond at any level can readily be sketched in, and the amount of cut required for desired depth, and the spoil to be disposed of in the dam and the banks can be roughly calculated.

A less laborious method which is usually satisfactory is to select some spot that would make a good shore and use a transit or hand level to find the corresponding shoreline at other points. This is done by reading a rod set on the selected point; and moving the rod up and down any slope in question until the reading is the same, at which place it will be on the same level as the original point.

Readings can be taken on the dam site and on high, low, and normal points in the pond basis, and distances measured with a tape or by stadia.

DAMS

Digging may be done according to patterns outlined previously, with one or more cuts made across the bottom of the pond and piled for the dam. Or the digging may be done parallel with the dam and all the spoil used in its construction.

A dam should fulfill three requirements. It must be high enough in relation to the spillway so that water will never flow over unprotected parts; it should be stable enough not to break, slump, or move under any conditions, and it should not leak.

Usually earth dams for small ponds are given a freeboard, or height above water, of two feet. If the spillway is wide, wave action very weak, and the material thoroughly consolidated one foot may be enough, but under reverse conditions, three or more feet may be required. For further protection, an earth dam should be covered with a strong sod, or bushes and trees.

Small masonry dams are usually built so that part of the dam is overtopped by the water and serves as a spillway. As long as the masonry is strong, no harm should result, and the expense of an extra structure is saved.

No dam should be built to hold a depth of over six feet of water, or any consider-

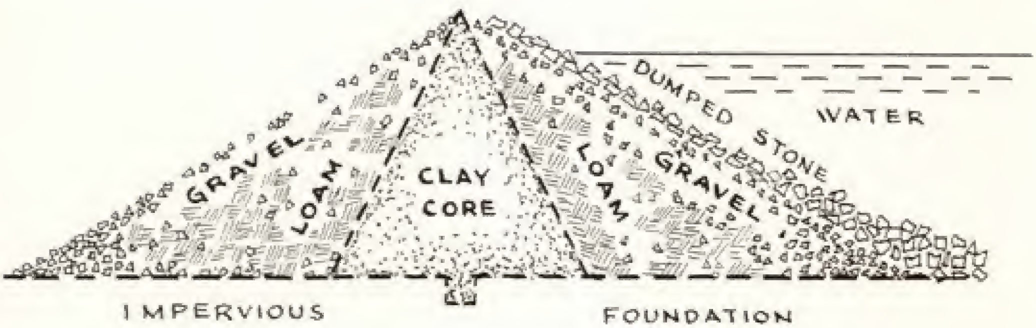


Fig. 6-17. Hydraulic fill dam

able volume of water which would flood an inhabited area if released, without competent engineering advice. In many localities, plans must be filed and permits obtained before building any dam.

Earth Dams. For stability, an earth dam should rest on a base of firm soil or rock without stratification dipping away from the pond. It should be well bonded to its base by removing vegetation (this is very important), and plowing or ditching parallel to the axis of the dam.

The dam should be at least six feet thick at water level, and slopes should not exceed one on two on the downstream face, nor one on three upstream. If the top is to be used as a roadway, it should be at least ten feet wide.

The soil used should be stable enough to hold itself up, to resist both the push and the softening effect of the water, and to carry any traffic or other loads on the top of the dam. It should also be fine grained and compact enough to give maximum resistance to movement of water through it.

Stability in the presence of water is best obtained by the use of broken rock or clean gravel, but these materials allow easy passage of water. Clay, and soils rich in clay, are best for sealing off water, but may be inclined to slump and flow when saturated.

Large Earth Dams. In large dams, a clay core may be used to stop the water, with loam or gravel faces to support the clay, as in Figure 6-17. In such dams, the type and amount of each material must be calculated. The dam may be built up in carefully compacted layers from material carried from pits in trucks or pans; or the fill may be mixed with water and carried to the dam in pipes laid along its sides. When carried mechanically, the clay core is usually built up a step or two ahead of the faces. The hydraulic method mixes all the soil types together, but as they come out of the pipe, the coarse material is dropped first, at the edge, and successively finer particles as the water flows inward. At the center a pond forms and fine clay and silt particles are deposited to build the core.

Small Dams. These methods are not well adapted to small dams. The expense of setting up hydraulic equipment can be justified only by large scale operations. Mechanical transportation and spreading is handicapped by lack of width. Even small trucks, pans, and dozers cannot work readily in strips less than eight feet wide, nor in comfort on less than twelve feet. The three sections would accordingly produce a width greatly in excess of that needed. A narrower dam could be built by the use of undersize equipment or hand labor.

A reasonably satisfactory dam may be made of mixed soil dug out of the pond or obtained nearby. This may be piled wet by a dragline or built up in compacted layers in the same manner as a road fill. Dusty soil should be dampened. If much sand or

gravel is included, it should be mixed with heavier soil, or placed on the downstream face as much as possible.

If the dam is built of dry, uncompacted material, it should be allowed several months and some soaking rains to settle it before using it to impound water.

If the soil is porous, the dam will leak unless sealed on the upstream side. It is not safe to wait for sediment in the pond to accomplish this as leakage may liquefy the soil and cause the dam to fail.

The upstream face may be covered with a blanket of clay, heavy soil, or a bentonite mixture.

Bentonite. Bentonite is a volcanic clay which absorbs large quantities of water, changing to a jelly that effectively seals soil against water seepage. It is used in many industrial processes and is available in most cities. The pellet size is more desirable for pond work than the powder forms, which tend to float on the water surface for long periods, and may be lost over the spillway.

A recommended practice is to mix one part of bentonite with four parts of sandy soil, or six or eight parts of heavy loam, and place a four inch layer of the mixture over the areas to be waterproofed. When more convenient, the pure material is spread over the ground and raked in. Satisfactory results are often obtained from more economical amounts, applied either in leaner mixtures or thinner layers.

Either bentonite or the mixture can be shoveled into a pond over leaks, and allowed to settle into them. This is best done when there is no overflow.

Usable Materials. Small stumps can be used in a dam if the fill is muddy so that it will form a close bond and fill cavities. It is good practice to cut roots back close to the butt. Boulders may be used in either wet or dry fills if the soil is carefully puddled or tamped around them, and they are not close to each other.

If the fill is rich in organic matter, considerable shrinkage must be allowed for in both height and thickness. Even after years of use, the dam may shrink still farther if the pond is dry for an extended period.

Cutoff Trench. If the soil on the dam site it porous or unsubstantial, a trench should be dug down to better material, approximately under the center line of the dam. This should be filled with clay, well tamped or puddled.

If a deep layer of peat is found at the dam site, it would be best to find another place for the dam. If this is impractical, the peat may be dug or blasted out, or compacted by sand hole vertical drainage. If the budget does not include funds for any of this work, the dam may be built on the peat, and access for machinery provided so that it can be built up later if it sinks. If bulges appear in the peat above or below the dam, they should be left as they serve to partly counterbalance the weight of the dam.

Settling and Cracking. In an all-earth dam, troubles to be guarded against are settling, cracking, slumping, seepage, erosion, and damage by burrowing animals. Settling is prevented by building on a firm base, using fill low in organic matter, and tamping or rolling it in thin layers if built dry. Cracking may occur in a dam with a high clay content when the pond level is low, and may be avoided by mixing in lighter soils. Such cracking rarely causes dam failure.

Slumping. Slumping may occur while building a dam with wet fill, and usually necessitates stopping work on the affected section until it has partially dried. Much more serious slumping may occur when water is impounded behind the dam before it is thoroughly consolidated. Wet fills that have not dried, or uncompacted dry fills which have not stood long enough to settle together, are apt to have this trouble. Seepage of pond water into the dam, softening

it, and water pressure giving it a push, act together.

Water in a pond exerts pressure against its shores, that tends to balance inward pressure from the water they contain. If the pond is drained, removal of the water support may cause extensive slumping, which may be disastrous if it occurs in a dam.

A dam or causeway separating two ponds is particularly vulnerable if the lower pond is drained.

For this reason, it is important to face dams with coarse, self-sustaining material that will resist slumping.

Seepage. No earth dam is watertight as there is a slow movement of water even through clay. Water working its way from the pond through the dam is usually called seepage only when it is sufficient in quantity to show on the downstream side, where it may make wet spots on the dam face or marshy patches below it. Aside from the loss of water, such seepage may damage the dam by liquefying it until it slumps; or by making channels of increasing size by washing out particles of earth. Once definite channels are established the volume of flow may enable it to tunnel and destroy the dam.

The seepage appearing below the dam may damage it by undermining, but more often merely produces soft wet areas that may detract seriously from the value of the pond area.

Seepage may be largely prevented by cleaning and scarifying the subgrade, careful construction of the dam, using sufficient impervious material, compacting it well, and allowing it to set before raising the water level.

The surest and most expensive cure for seepage in an existing dam is trenching along it, with a hoe shovel or clamshell, to solid foundation, and building or pouring a masonry core. This may be quite thin if of dense masonry treated with waterproofing on the pond side. Since a leaking dam is liable to have extensive soft spots in its interior, such a ditch may be dug safely only if the pond has been drained for several months, or very heavy bracing is used.

Driving a single line of sheet piling, or tongue and groove sheeting down the center line of the dam, with grouting on the upstream side, is often effective.

The leaks may be stopped by laying a clay blanket on the pond side. The pond should be drained, if possible, to allow inspection. The leakage may be through the upstream side of the dam or in the pond bottom nearby. If the spots cannot be found, clay or heavy soil should be laid six inches to two feet thick on the whole face of the dam, and on the bottom, back about twice the height of the dam, and should be thoroughly tamped. The slope should be gentle, one on four to one on six, and the clay should be covered with gravel or cobbles where subjected to action of the waves. If the leaks are found, digging them out to the depth of about two feet, and tamping in heavy earth patches, may suffice.

Impervious patches should never be applied on the downstream side, where the water is leaking out, if the leaks are low on the face. The water will generally work into or around the patch, soften it, and force it out. If the patch holds, the water held in the dam may liquefy parts of it, causing slumping and possibly complete failure.

The best treatment for the downstream slope of a leaking dam is to face it with gravel, with an underdrain below the bottom of the dam opening into the outlet brook, as in Figure 6-18. The first coating of gravel should be bank run to allow the passage of water, while holding back any soil particles carried with it. Over the bank gravel should be clean coarse gravel or crushed stone to correct any tendency toward sliding when saturated. If the area

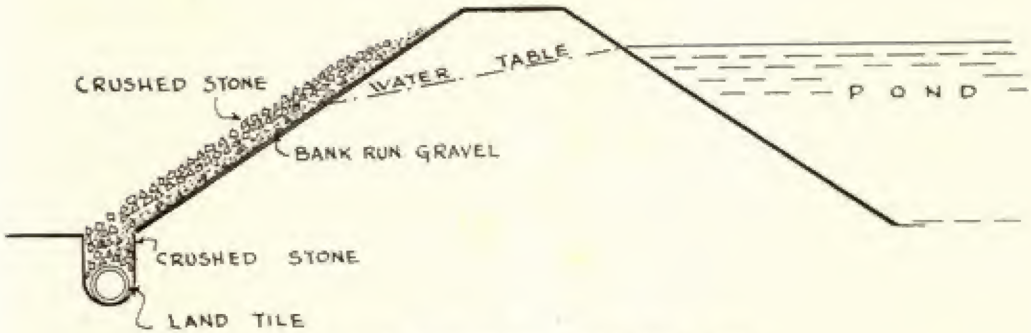


Fig. 6-18. Seepage apron, small earth dam

is to be planted with grass, stone should be covered with straw, hay, or cut weeds before placing topsoil.

This gravel blanket does not reduce loss of water, but it does stop damage to the dam and eliminates surface wet spots.

Seepage at the foot of the dam may be kept underground by tile and gravel, or stone drains, of the same type used in draining farm land.

If the dam is of pervious material the methods suggested later in this chapter for stopping seepage into porous soil may be of use.

Overtopping. If the water is allowed to flow over the top of an ordinary earth dam, it may cut a gully to the bottom of it, draining the pond, wrecking the dam, and perhaps causing flood damage below. Freshly built dams are much more subject to damage from overtopping than old established ones that have set and are covered with vegetation.

Overtopping is due to the dam settling or slumping below a safe height, or an inadequate or too high spillway allowing the pond level to rise too much.

If a dam starts to slump, the water should be drained if possible, the dam allowed to dry, and then be rebuilt with more or better material. If it is not possible to drain the pond and pumping or siphoning are not practical, the dam should be reinforced by putting first gravel, then a heavy fill of coarse rock on the downstream side. An attempt should be made to puddle or blanket the pond side, and the top should be filled to grade. If it settles badly without slumping, the top should be built up, preferably with compacted fill. Sandbags, if obtainable, make an excellent temporary stop.

Sometimes a dam can be saved by partly draining the pond through a trench dug in firm ground nearby. Undisturbed soils can often carry a heavy flow of clean water without severe gullying, particularly if reinforced with roots, boulders, or brush mats.

Repair. When a gullied dam is fixed, the sides of the break should be smoothed and sloped sufficiently so that the fill can be tamped against all parts of them, but it should not be cut into a straight ditch. The bottom should be dried up if possible. Fill should be dumped on the edge and pushed or shoveled down gradually, while men at the bottom spread it in thin layers, tamping or tramping it thoroughly. If the break is large enough to allow machinery to work in it, it can do most of the spreading and compacting, but the bond with the walls must be done by hand. Dusting bentonite against the sides while filling should prevent seepage along them.

If it is not practical to dry up the bottom, fill should be dumped and kneaded until the water is absorbed into a stiff mud on which a layered fill may be built.

Burrowing Animals. Earth dams may be damaged by animals burrowing part or all the way through them. Muskrats make holes which run under water to well under the bank, where they rise above the water. Such tunnels will cause leaks only when

they give water access to some line of weakness that did not go through to the pond, or which had been silted shut. Muskrat damage can be largely avoided by using a low dam not containing enough dry ground for home building, or a wide one without porous veins.

Crayfish will at times dig burrows all the way through a dam, creating a water channel large enough to enlarge by erosion, unless a fortunate cave-in should block it. This damage is most apt to occur in soft peat soil and it may sometimes be cured by injections of cement grout.

Burrowing animals may be discouraged by including quarter inch mesh wire in the underwater part of the upstream slope. This affords fairly good protection for a number of years. It is usually laid on the dam, and six inches to a foot of fill are spread on it.

Masonry Dams. Masonry dams may be used instead of earth fills. They are most suited to comparatively narrow sites with firm bedrock near the surface of bottom and sides. Reinforced concrete is the strongest construction, but field stone masonry is more attractive and may be less expensive in inaccessible spots.

Earth and decayed rock should be cleaned off the dam site, and the bedrock shaped or gouged in such a way that the dam will not be able to slide on it in any direction. Holes two or more feet in depth should be drilled in the rock, and reinforcing iron cemented into them so that it will project into the concrete or other masonry.

If the dam is to be more than a few feet high, it is advisable to have an engineer or a geologist check the ground as fractured rock can make a leaky and unstable foundation.

The dam should have a bottom thickness of at least two to three feet for every three feet of height.

Masonry Cores. A masonry core dam consists of a thinner wall, preferably reinforced concrete, with earth piled on both sides. The masonry does not extend much above the water line, and is ordinarily buried under earth. The core seals off seepage, and the sides support and protect it. It must resist the difference in pressure between the wet and dry earth on its two sides. Thickness is about ¼th of height.

The core should be founded on a firm, impermeable material, preferably rock. The original surface is ditched for footings. The sides are carried into the banks until they meet rock, or until they are far enough from the water to make seepage unlikely. Rock should be roughened to hold the masonry against shifting.

The core is built and allowed to cure before placing the earth fill. The upstream face should be painted with waterproofing. If its ends are not keyed into rock, they should be fitted with vertical metal baffles sealed to the concrete, and the fill near the baffles should be mixed with bentonite. Failure to take these precautions may lead to serious leakage around the core.

Fill should be placed on both sides of the wall at the same time to avoid unbalanced pressure. If the dam is high, the fill should be carefully compacted. If it is low, this is not necessary unless final grading is to be done immediately.

The masonry core dam is the safest and most satisfactory construction for ponds, but is too expensive for casual use.

Removable Wood Dams. If a small pond is built on a small but fast flowing stream subject to flood, there is not only the danger that earth or weak masonry dams will be washed out, but that, if the dam holds, the pond may fill completely with mud and debris in a single season, because the slowing and widening of the stream causes it to drop a part of its burden.

A removable wood dam may be used to advantage under such conditions. If the stream is narrow, ten feet or less, a heavy,

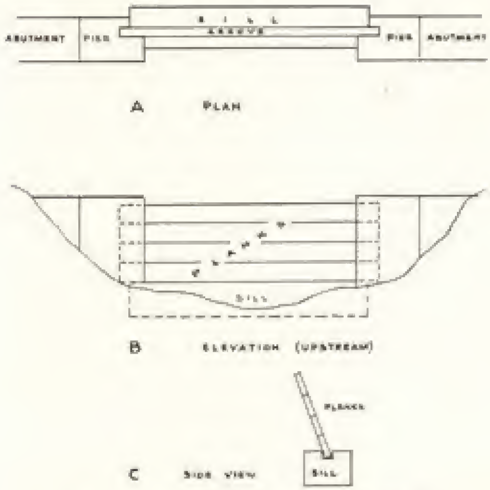


Fig. 6-19. Removable wood dam

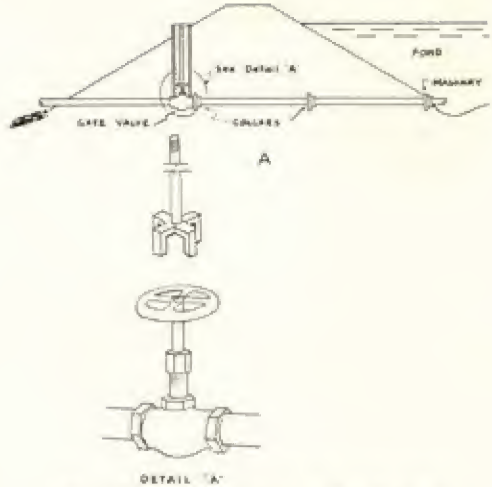


Fig. 6-20. Drain pipe and gate valve

well founded masonry wall is put on each bank, having slots to receive two to three inch plank, as in Figure 6-19. A masonry sill, similarly slotted, connects the piers on the stream bottom. Planks cut to the correct size and length are slid down the pier slots, resting on the sill and on each other, until the desired height is achieved. This structure will leak but will impede a brisk stream enough so that part of it will flow over the top board, and the desired water height may be maintained. If the stream shrinks, the leaks may be reduced by jamming a tarpaulin in the sill slot, upstream, and pulling it over the dam face and top, and tying weights on the downstream side. Or tongue and groove planks may be used to cut leakage, with the top plank fastened down and all the joints packed.

When a flood is expected, or pond use stopped for the season, the planks may be taken out and stored, allowing the stream a clear passage.

DRAINS

Gate Valve. When possible, means should be provided to drain a pond for repair, cleaning, and other purposes. The best, but most expensive, means is to place an iron pipe under the dam, connected with a gate valve, which may be located in the dam or at either end. Figure 6-20 shows an installation in which the valve is in the downstream face below frost line. To prevent burial and clogging, a vertical eight inch pipe placed over the valve wheel extends to the surface, where it is plugged or covered. The valve is opened or closed by removing this cover, and turning the valve wheel by means of a jaw on the bottom of a rod which can be turned from the top.

If the cover should be left off, and the vertical pipe filled with dirt and trash, it may be jetted out by the use of an engine-driven water pump, delivering water at pressure through a small pipe which is pushed down inside the casing, where it can break up and wash out the debris.

Elbow Drains. A much less expensive installation which can be used in climates where freezing is not expected is shown in Figure 6-21 (A). An iron drain pipe under the dam is fitted with an elbow on the downstream end into which a vertical pipe is threaded. Space is provided so that this pipe can be turned into a horizontal position.

If the open end of the pipe is higher than the water in the pond no water will move through it. If it is lower, the water will flow through it until the pond level is lowered to the same elevation. The pond

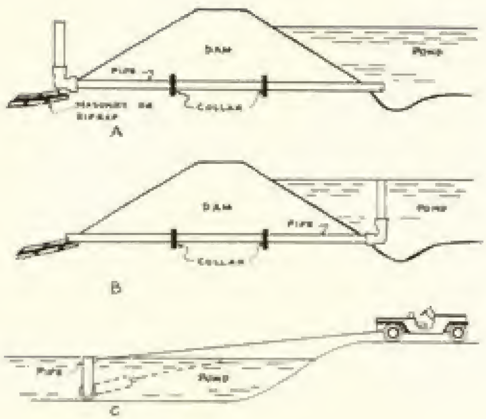


Fig. 6-21. Elbow drain

level can therefore be adjusted to any height desired by turning the pipe up or down.

In cold climates, the exposed pipe would be subject to breakage because of water freezing in it. This is not likely to occur if the movable pipe is placed in the pond as in (B) because of less severe freezing and inward pressure of pond ice. However, the water makes the pipe difficult to get at so that it must usually be moved by a line stretched to shore, as in (C). This will not pull it into a horizontal position and may have difficulty raising it from down position also.

A more satisfactory arrangement for underwater use is shown in Figure 6-22. The drain pipe is extended by means of a tee, a close nipple, another tee, a short pipe, and a cap. The tees are fitted with pipes long enough to reach the surface of the water. These are set at an angle of about 45° from each other, and the tees welded together. One of the pipes is capped and a ring fastened to it.

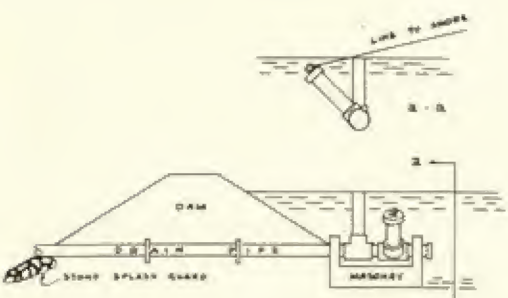


Fig. 6-22. Elbow drain with pull arm

This apparatus rests on a small block of concrete, which is cast around the edge of the drain pipe and around tar paper wrapped around the end pipe, but is enough below the tees so that they can turn.

Control is by a rope or cable stretched from the ring, past the vertical drain pipe to the shore. A pull on this line, by hand or machine, should raise the ring pipe and turn the drain pipe down. The drain pipe can be raised by pulling the line from the opposite bank.

With some risk of twisting the end off instead of turning it, the masonry block may be omitted and the outer tee replaced by a street ell welded to the inner tee.

The threads should be treated with waterproof grease or plumber's dope, and wrought iron fittings should be used if possible.

Metal pipe is expensive in large sizes and six inch is about the minimum for a pond drain, except for use in dry seasons only. Considerable expense may be saved by using concrete or tile pipe under the dam, connecting it near the end with metal pipe to the valve or other drain arrangement.

Vertical Tile. An overflow or trickle drain can also be made entirely with tile. A pipe is laid under the dam, ending on the upstream side in a concrete junction box, as in Figure 6-23. From this a tile pipe with joints sealed with soft mastic rises to the surface. One of the pipes may have to be chipped short to obtain the proper height. The pond height is limited by overflow into the pipe.

The pond is drained by pulling the top pipe out of its joint and removing the next section when the water has gone down sufficiently, repeating the process until the bot-

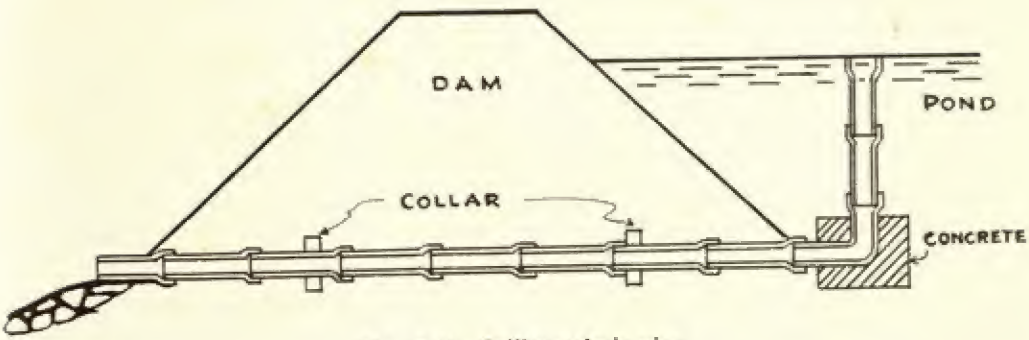


Fig. 6-23. Spillway drain pipe

tom is reached. Sometimes the whole pipe will pull out of the box and drain the pond all at once. At other times, a pipe may refuse to move and may have to be broken with a hammer or crowbar.

The overflow type of pond drain serves to some extent as a spillway, but a regular or emergency spillway also should be provided for flood conditions, and because of the possibility of the pipe becoming clogged.

Pipes reaching the surface of the water can be protected against external ice pressure by tying several sticks or boards to the outside.

Plugged Pipe. Plug drains are shown in Figure 6-24. A stopper is made by reinforcing a piece of half inch to one inch marine plywood with iron bands, passing a cable through it and placing it over the pond end of the pipe. If the pipe is rough or chipped, it may be smoothed over with cement grout and painted with a soft mastic.

As the water rises, its pressure should hold the wood firmly against the pipe. If any leakage occurs, the contact may be packed with clay and tied with burlap, or the pipe end buried in mud.

The pond is drained by sliding the wood off the pipe by means of the cable and a tractor or car on the bank. Sometimes wood and concrete will adhere so firmly that the pipe separates at the next joint and comes out with the plug, in which case it can be reset after the water goes down. If the end pipe is set in masonry it will stay put.

The upper end of the cable can be fastened to a buoy or to an anchor in the bank.

A permanent plug such as that shown in (B) may be placed in the pipe and the pipe pulled with a cable. Hammered-in wood plugs are satisfactory for diameters

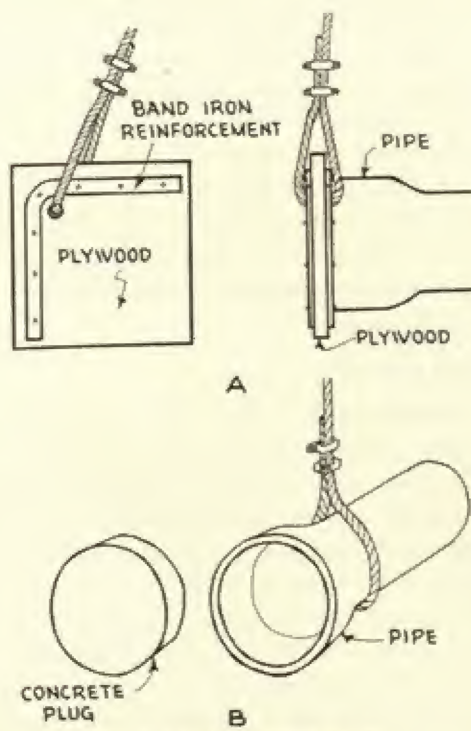


Fig. 6-24. Drain pipe plugs

up to four inches, and reinforced concrete for larger sizes.

A drain pipe should be straight with good access to the lower end, so that if the plug-pulling device doesn't work, an opening can be hammered or blasted through.

Drain pipes are a source of weakness to dams and must be carefully installed. It is best to place them before the dam is built, as this eliminates the difficulty of making a proper bond between fill and the wall of a ditch. Pipe joints should be watertight.

One or two collars of metal or masonry should be built out from the pipe, as indicated in the illustrations, and sealed to it by cement or welding. These will discourage seepage from following the outside of the pipe and cutting a channel along it. Clay, or soil mixed with bentonite, should be tamped or puddled around the pipe and the collars.

The first layer of fill should be spread rather evenly along the masonry pipe, as a full load in one spot might push it down enough to open the joints. If the ditch bottom is not firm, the pipe may be set on a reinforced concrete slab the width of the pipe and up to six inches thick.

A wood box, 3 feet square or larger, may be built of rot-resistant wood around the upper end of a drain pipe and topped with bronze screen, to keep fish in while lowering the pond.

SPILLWAYS

Construction. Ponds which are made by excavation only, and do not raise the original water level, usually overflow through stabilized streams or channels that do not require any artificial protection against erosion. If an earth or masonry core dam is used, however, an artificial overflow channel, called a spillway, must be prepared.

A spillway may have a surface of any material that will resist the destructive action of the water which might flow across it. A steady flow calls for a structure, usually of stone or concrete, but occasionally wood, metal, or asphalt. A spillway that carries water rarely, as one which is intended to care for floods in excess of the capacity of a masonry or pipe spillway, or to provide for occasional overflow of a normally static pond, may be planted with grass or other well rooted vegetation.

Spillway size may be calculated on the basis of the area drained, type of land and vegetation, and rainfall records in the same manner as culverts. However, a greater margin for safety should be allowed.

It is good practice to keep the spillway and the dam separate if possible, as each is a source of weakness to the other. A recently constructed dam ordinarily lacks the stability necessary to support heavy masonry, and it is difficult to get a leakproof bond between dirt and stone. Any leaking through or around a spillway will be much more destructive to an earth dam than to a long established subgrade. On the other hand, practical and esthetic considerations frequently require placement of the spillway in the dam.

If the dam including a spillway has a masonry core, the two structures can be combined. However, the core must be widened or buttressed, or the spillway provided with additional foundations as firm as the core wall. If the spillway is supported by a thin core wall and dirt fill, and the fill settles, the spillway will be left supported only at the core, and may break, or may twist and break the core. A preferred method is to extend the core footings far enough to carry piers to support the spillway.

If the overflow is to be carried around the dam, standard practice for masonry structures may be followed. Two more or less parallel walls carrying the water race, which may be a curve or a series of steps, is a standard type of construction. The structure is strongest if of reinforced con-

crete well tied together, but stone and mortar make a more attractive appearance. The fill under the water race should be clean sand or gravel with good bottom drainage if the ground freezes in winter.

Settlement. If the spillway is to be part of a newly made dam, it may be based on the fill material, or may have footings in the native soil underneath the dam. In the first case, any settlement is liable to tilt or break the spillway and to settle away from it leaving channels for leakage. In the second case, the masonry will stand firm while the dam settles under it and away from it. If the structure includes a core wall long enough to tie into the earth on each side, such settlement may not be serious.

Grouting. Leakage under a masonry spillway surface, resulting from dirt settling away from it, may be stopped by drilling holes in the masonry and pouring or pumping a cement and water grout into them.

A grout injector may be an air pressure tank or a pump. The tank is provided with an agitator to prevent separation. It is partly filled with grout and tightly closed. Compressed air is piped into the top of the tank, forcing the grout out through a pipe or hose in the bottom. The tank is opened and a fresh batch of grout poured in as often as necessary. Air should not be allowed to enter the outlet hose.

Special pumps may be purchased, or a fluid grease dispenser or a tractor grease gun used. Pumping can be continuous, with extra grout added as necessary.

The holes are drilled or punched to a depth where the leaks are suspected. The grouting tube may be fitted with a rubber collar to fit the holes and held in place by hand, if low pressures are used. For high pressures, a threaded iron pipe is cemented into the hole some days before and the grout pipe coupled to it.

The grout forced underground may penetrate and seal the leaks, it may be washed away by water or may escape to the surface of the ground. If possible, the pond level should be lowered to stop the water flow during grouting. The whole area should be watched for the appearance of grout, particularly at the leakage points.

A very thin grout made with forty-five gallons of water to a sack of cement is good for sealing fine porous soil, but will escape readily through small channels. The thickest grout used, four and a half gallons of water to a sack of cement, will escape only through large openings, but does not seal fine passages effectively. Sand mixtures are not recommended for amateur use because of the tendency to separate, but sawdust or fine shavings may be mixed with grout used from pressure containers if the grout is otherwise washed out by water which cannot be stopped.

If grout is applied at a pressure of more than a few pounds, care should be taken that it does not lift or break the spillway, or even split bedrock beneath. A tractor grease gun can develop pressure of thousands of pounds per square inch, and will break up strong masonry with little effort.

All grouting equipment should be thoroughly cleaned immediately after finishing the job, or for any shutdowns of more than a few minutes.

Detailed information on the use of grout for stopping leakage and for other purposes may be obtained by writing to the Portland Cement Association, New York 17, New York.

Wood Spillway. Trouble from settling under a spillway may be avoided by putting in a temporary structure upon completion of the pond, and removing or destroying it when settlement is complete, and building the parmanent spillway. Tongue and groove plank made into a box is a satisfactory construction. The dam surface on which the wood rests should be coated with bentonite, clay, or other heavy soil, and pud-

dled until semi-fluid. The spillway should be stirred around or vibrated when set, and mud packed in along the sides.

A wood spillway may give satisfactory service for a great many years under favorable conditions.

Horizontal Pipe. Concrete, tile, or corrugated steel pipe of large size may be used, either as described under drains or laid horizontally through the dam at water level, with the same precautions against seepage.

WATER SUPPLY AND LOSSES

Water Supply. The ability of a pond to remain nearly full of water through a dry season is to a large extent the measure of its usefulness, except in semi-arid sections where it is considered a success if it retains any water at all.

A pond level is kept up by water entering it through rainfall, surface wash, springs and seepage, and streams. It is lowered by evaporation, outflow, leaks, and seepage through sides and floor.

Once a pond is built, little can be done to add water to it except by pumping water from a well, by windmills or engine-driven pumps, or more rarely, diverting water into it. It is therefore important to locate and build it in such a manner as to take full advantage of sources of water.

Ponds dug in swamps may depend primarily on the water table existing before work is started. If possible, fluctuations of this should be watched for a year or two. A hole may be dug by hand in the wet season until the bottom fills with water. If the water dries up the holes should be deepened. The water table can be followed down and its changes observed in this way.

A dug pond may cut into active springs or extensive seepage areas which had previously been draining below the site, so that the pond may keep a higher level than the ground water did. On the other hand, the swamp water might overlie a layer of clay or hardpan, which, when cut, would allow all the water to drain down into unsaturated porous soil, in which case it might be difficult to keep water in the pond.

The best way to estimate the water supply is to measure the drainage area. Figure 6-25 indicates approximate requirements throughout the country.

Seepage into Porous Soil. Outgoing seepage can be greatly reduced and sometimes stopped altogether by keeping mud in suspension in the pond water for some time. The water in seeping out of the pond takes the suspended particles with it and lodges them in the fine passages through which it travels, thus clogging them up. This process operating naturally over a period of years makes possible the existence of rain fed ponds and swamps on sand dunes and gravel banks, high above the water table.

Digging in a pond will keep it muddy, as will driving livestock around in it several times a day. Fine grained silt, powdered clay, or pellet bentonite may be scattered on the water with hand shovels, preferably when there is no overflow.

If the water is leaking through channels too large to be plugged by sediment, a layer of clay or a soil-bentonite mixture several inches in thickness should be spread over any outcrops of porous veins. If this fails to hold, the pond should be pumped dry and any leakage holes appearing in the clay should be dug out and filled with the blanketing material to a depth of a foot or more.

If the porous vein is comparatively thin and close to the surface, it may be sealed by injections of cement grout in the same manner suggested for spillways.

If leakage is along sod or brush which was not removed before placing fill for the dam, it may be stopped by chopping and mixing. A mechanical tamper such as the Ottawa Hydrahammer can drive a narrow tool several feet underground, and repeated blows struck close together will mix the vegetation into the dirt so thoroughly that

A general guide for use in estimating the approximate size of drainage area required for a desired storage capacity in either excavated or impounding reservoirs. The numbers on the chart show the number of acres of drainage area required for 1 acre-foot of water impounded.

Courtesy U. S. Department of Agriculture

Fig. 6-25. Drainage area map

it will no longer provide water channels. Additional fill can be added to the surface if necessary, and a wide face tamping tool used for compaction.

Seepage along the old ground surface may cease when the vegetation rots, but this cure cannot be depended upon.

Seepage cannot be stopped entirely but will fall to a very small amount in a well sealed pond, particularly if the water level is not high enough to create a strong pressure toward a nearby low spot.

Movement of ground water is often nearly horizontal so that much of the loss from a pond is through the banks rather than the bottom. This is one factor in the excessive shrinking of some small ponds during dry spells.

Evaporation. Evaporation acts constantly to remove surface water. It varies with heat, humidity, and exposure to sunlight and wind, and may lower the level of a stagnant pond from five to fifteen feet during a summer. This loss is most pronounced in desert regions.

The rate of evaporation is higher on small ponds than on large, and on shallow ponds as compared with deep ones. A number of factors are involved: The banks heat more readily than the water surface; capillary attraction draws water several feet up on the banks, thus increasing the surface exposed to evaporation, and a large body of water warms more slowly than a small one.

This loss from the water surface may be reduced by shading it with trees, but it is a question whether the trees do not use as much water as they save. If they are set well back from the edge, they may find a

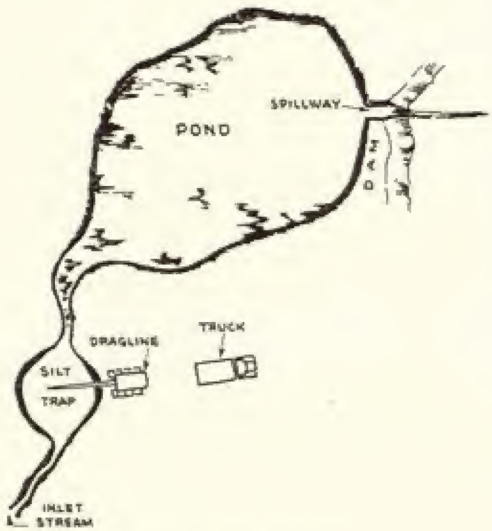


Fig. 6-26. Silt trap

large part of their water supply elsewhere.

Dry Land Ponds. Losses of water through seepage and evaporation assume their greatest importance in ponds designed to fill with surface run-off in the winter or spring, and to hold this water through a dry summer, even though the water table drops many feet below their bottoms.

Such a pond should be so located that the drainage from a large area will flow into it; not only so that it will fill even in years of subnormal rainfall, but so that it will get the fullest advantage from any freak rains that might fall in the summer. But it should not be placed in the channel of a stream having enough force to fill the pond with sediment during flood time, or to require an unreasonably expensive spillway.

Such a pond may generally be dug in the dry season without any interference from ground water. Pans, bulldozers, draglines, other shovel rigs, or horse or tractor drawn scrapers and scoops may be used. Techniques are similar to those used in borrow pits and cellars, except that banks must be sloped, not more steeply than one on one, and it is usual to place a large part of the spoil so as to build up a dam.

For detailed discussion of the locating and building of such dry land ponds, the reader is referred to Farmer's Bulletin No. 1859, entitled "Stock-Water Developments," issued by the U. S. Department of Agriculture, which can be obtained from the Superintendent of Documents, Washington 25, D. C.

POND MAINTENANCE

Silting. Silting is a problem common to most ponds and reservoirs. Lakes of all sizes are short lived geologically, because incoming water deposits sediments that fill them, and water flowing out tends to deepen its channel.

The amount of silting will depend largely on the local conditions. Steep slopes, cultivated or bare land, and fast stream flow bring heavy loads of sediment into ponds and cause them to fill rapidly.

Wastage of soil from farm land can be greatly reduced by contour plowing, terracing, and planting steep slopes to permanent grass or trees, with beneficial results to the land, the stream, and the ponds.

If it is not possible to alter watershed conditions, silt traps may be constructed. These may consist of small ponds built above the main one, or a very deep hole on the upstream end of the pond. Such traps should be so located that a dragline shovel and trucks can reach them for periodic cleaning.

Mud deposits found in ponds and lakes are made up of soil brought in by water or slumping from the banks; dust, leaves, pollen, and other debris falling from the air, and remains of plants and animals living in the pond. A combination of these sources usually produces a soft black mud which dirties and shallows the water. Near inlets and steep banks it may be chiefly silt or sand, and away from shores it is largely organic.

Removal. A hydraulic dredge removes

such a deposit without draining the pond, but its use is seldom practical. It is apt to be too costly to transport and launch, there is unlikely to be enough water inflow to keep it supplied and adequate disposal areas are hard to find.

Removal by machinery usually requires draining or pumping out of the water to avoid distributing disturbed mud throughout the pond.

After draining, the mud deposit will often be found to be so soft that it will not support machinery safely even on platforms. Given time, it will drain and compact so as to be fairly firm, in which condition it will not only support platforms but will stay in a dragline bucket. This hardening process, which may reduce its bulk as much as 80 percent, can be greatly accelerated by hand ditching into the subsoil for more thorough drainage. The ditching, however, is a sloppy job, and will be very discouraging at first because of mud flowing or slumping into the ditch and blocking it. The first digging should be very shallow and can be gradually deepened as the banks drain.

If the pond is narrow and accessible enough so that all parts can be reached by a dragline on the banks, or if the mud overlies firm material that will support a dozer which can push the mud to a dragline, it may not be absolutely necessary to let the mud dry. If it is too thin to be picked up in the bucket, digging the ground under it several times may suffice to get enough of it out. In any event, such undercutting will eventually lower it so much that it will no longer be a nuisance.

It is seldom practical to just skim even dry mud off the old bottom. At least several inches of native soil are ordinarily dug with it, and this opportunity is often taken to deepen the pond substantially. In some cleaning methods, it is necessary to take enough subsoil to build firm piles.

The cleaning process differs from the original digging in the usually shallower cuts, the peculiar nature of the mud, the fact that trees and landscaping on the banks often must not be disturbed, and the undesirability of reducing the pond area by piling spoil inside it.

Bottom mud is generally useless for agriculture when freshly dug, but makes excellent topsoil after curing in piles for a year or two. Mixing with sandy subsoil speeds curing and improves its quality. It is often necessary to add lime to correct acidity.

Dragline. If a dragline can do the necessary cleaning from the banks, the problems are chiefly avoiding or cutting trees, and providing either places to pile the spoil or means of access for trucks to haul it away.

If the width is too great for the boom length, an unassisted dragline must work from the pond bottom, usually on platforms. From there it may pile spoil on the banks to be leveled off later; against the banks, to make a new shore for a smaller pond; load it in trucks on the bank, or build one or more windrows in the pond to be trucked out later.

Trucking windrows must contain enough inorganic soil so that they will become firm as they dry, and must be high enough so that capillary water will not keep them soft. This height will vary from about three feet for a sandy mixture to seven to ten for silt or clay. Lower piles, or any piles containing a lot of humus, may require a surfacing of better soil or gravel before they will support trucks. The height of the roadway will be substantially lower than that of the top of the original windrow.

The dragline may roughly level the piles as it builds them, or this work may be left to a bulldozer. It may be advisable to use the lightest dozer that can do the work, as unexpected soft spots may be found, due either to slower drying of sections of heavy soil or excessive amounts of humus in spots.

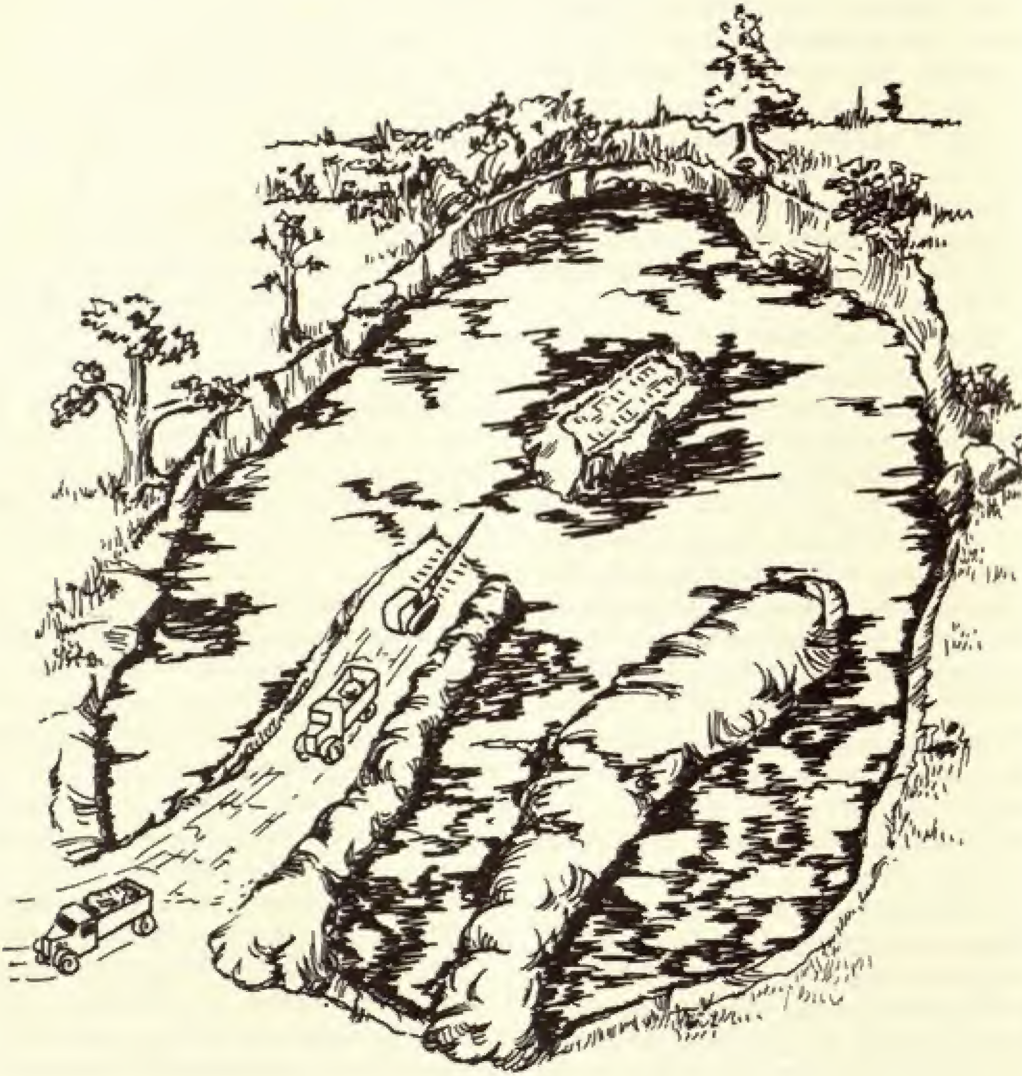


Fig. 6-27. Trucking out piled mud

Since cuts are usually shallow near shore, and trees may interfere with maneuverability, it may not be practical to build the piles large enough to make a good land connection, in which case extra fill might be trucked in to bridge the gap.

When the windrows have dried and been leveled off for a roadway, the dragline can walk out to the end of one, possibly with the precaution of using platforms or poles, and dig it back from the end, loading trucks backed to it from the shore. It may just dig the piled material, or go down into the pond, either to deepen it or to obtain fill. Sections of roadway may be left to form islands.

Use of this method involves deepening the pond six inches to two feet or more. The double handling, the trucking, and the volume of material to be removed may make it prohibitively expensive for large areas, although it results in a pond which is better than new.

Dozer. If the bottom is firm enough to

Fig. 6-28. Pushing mud up slot ramp

support a dozer, and if the mud is thick enough so that a good load will stay in front of the blade, a dozer may provide the fastest and cheapest cleaning job.

The mud can be skimmed off gravel subsoils with little mixing. On softer footings, or wet soils which churn to mud readily, several inches may have to be taken with the mud. In any case, the digging down need not be as deep as with dragline work.

Disposal of the spoil may be a critical problem. It is liable to be too sloppy to pile up high enough for a bank, and to contain too much organic matter to make a satisfactory shore.

It can often be pushed out. The average pond edge is too steep for a dozer to climb with a load, so a ramp or ramps must be cut in it. If the shore is a dam, with low ground beyond, very liquid muds can be trapped in the ramp entrance and pushed through. Because of light friction, a dozer may push five to ten times its normal yardage on each trip through the slot, but a part of the volume will be water.

The ramp is apt to soften and break down, particularly at the bottom. Also, disposal areas at its head may fill up rapidly. For this reason, a number of ramps are liable to be required, and backfilling these later may be a major project.

The shovel dozer with grousers bolted on every fourth or fifth shoe on each track is the preferred tool for this work. The widely spaced cleats do not clog with mud. In cutting through heavy deposits, a shovel dozer is more adept at side casting than a standard dozer, and can backdrag material out of bad spots. When this is done by filling the bucket, it may be necessary to float it while backing to better ground, as lifting it tends to make the front of the machine sink in. This machine can often unstick itself by using the bucket dump as a pushing or pulling device.

The second choice is a wide gauge bulldozer. It usually has wide shoes that reduce its tendency to sink, and the width gives extra leverage for turning with loads on slippery footing. If grousers are worn down, a few of them can be built up to provide non-clogging traction.

When the bottom is reliably hard, a large dozer may be used. It is desirable because of greater production in both the volume of mud moved and area left cleaned by a single pass. It can also back into a deeper layer of soft mud without getting hung up than smaller machines with less

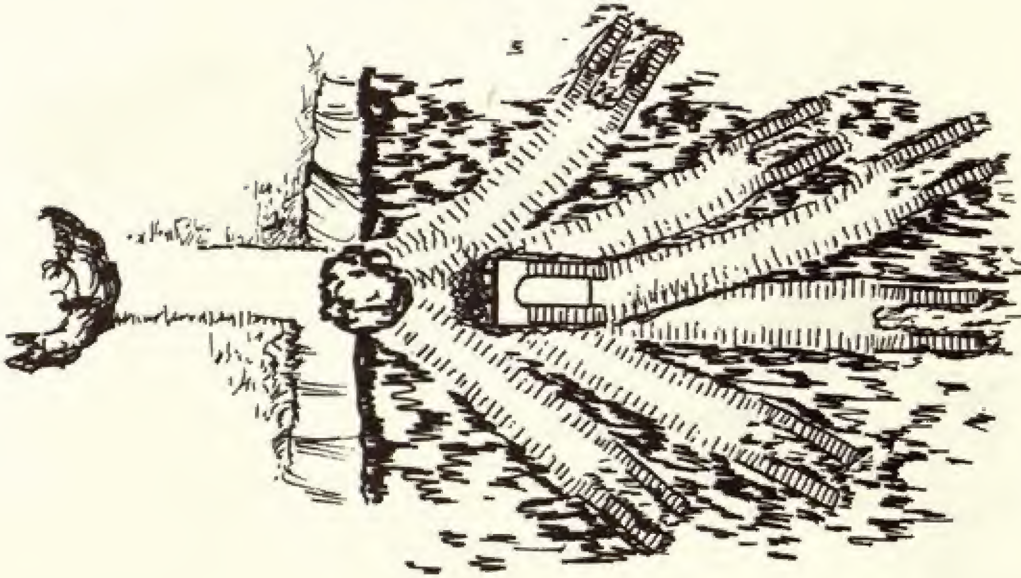


Fig. 6-29. Gathering mud near ramp

clearance.

On soft or doubtful bottoms, lighter machines are much less apt to get stuck and are easier to rescue if they do.

Saturated clay, silt, or very fine sand may look and act firm when work starts, but soften under the weight and vibration of machinery. This change will be caused much more quickly by heavy than by light units. However, such soil will often continue to give adequate support to a dozer as long as it keeps moving, even after becoming too soft for comfortable walking. No machinery should be left standing for any length of time on it, particularly if unattended.

When a dozer is used for swamp digging, means should be provided for prompt rescue in case the bottom proves too soft, or careless operation gets it stuck. If the dozer does not have a winch, a hand or machine winch, or equipment capable of exerting a heavy pull, should be on the bank with sufficient cable or chain to reach any part of the area. Cut green saplings and hand shovels should also be available.

Drain holes in the flywheel and steering clutch housings should be plugged to prevent the entrance of water and mud. Plugs should be taken out periodically to drain any oil that might leak into them.

Fully sealed rollers which are greased on a twice a year schedule require no special attention. Other types may require greasing every two to four hours to prevent mud from working past the seals. Sand in the mud may make it very abrasive so that track wear may be several times as rapid as normal.

Under average conditions, dozer work in a pond bottom offers considerable danger of getting bogged down, and conditions are often found to be so sloppy that little effective work is done. But when it works, it's fine.

Ramps. A bulldozer ordinarily cuts a ramp by digging from the side, parallel to the bank. The last few yards on the pond edge may be pushed out into the pond and to the side, and brought back up with the mud.

A shovel dozer may make the main cut in the same way, but is more likely to cut

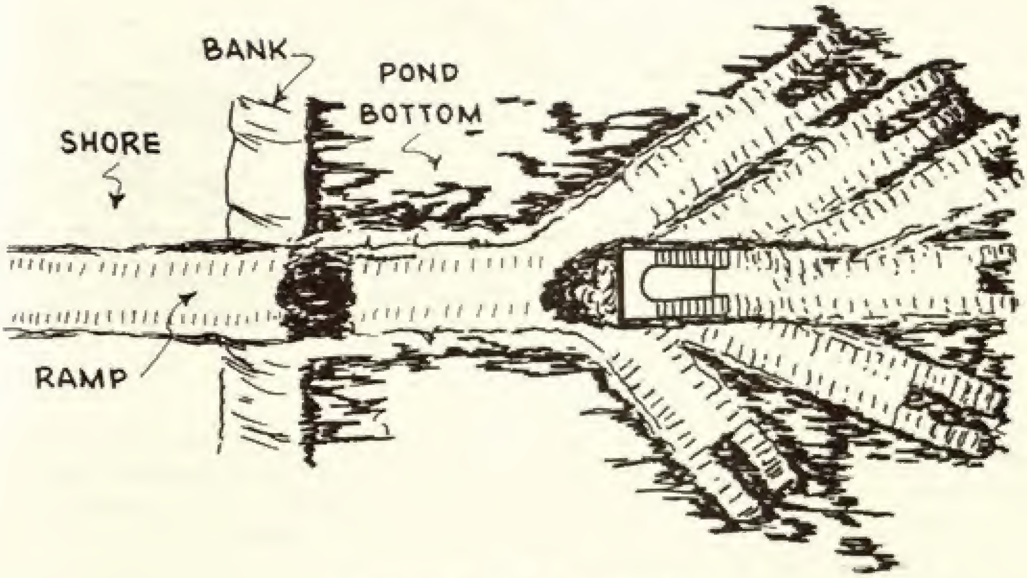


Fig. 6-30. Cleaning far section first

it lengthwise from the top, facing the pond and carrying or dragging the spoil back up it. It will not need to push as much out into the pond.

The ramp should be at the easiest possible gradient to facilitate pushing large loads and to minimize churning under the tracks.

When the ramp is roughed out, the dozer is backed into the pond mud until a good load is ahead of the blade or bucket. This is then pushed through the ramp to the disposal point, or parked in the ramp to be moved along with an additional load or loads.

The floor of the ramp will usually soften from absorbing water out of the mud being moved over it, and it will be worn down continuously by the push of the tracks and cuts by the blade. These effects are liable to be most severe in the pond at the foot where the dozer turns upward for its climb. A deep hole may be gouged here which will usually fill with a very thin mud. This ordinarily does not bother the machine any more than the same quantity of water, but will eventually reach the fan or other non-submersible parts, and the ramp will have to be abandoned or its foot relocated.

Such a hole may be convenient in freezing weather as the tractor may be placed in it overnight, so that the tracks will be under water and the mud on them will not freeze. This will save a long and messy job of putting it up on blocks and of cleaning and hosing it at the end of the day. It is of course not practical unless the bottom is entirely safe.

The cleared space may be widened by other cuts fanning out from the ramp. This uniform expansion of area is not particularly efficient from the pushing standpoint, as mud tends to spread on each push over ground cleaned by previous passes, and both mud and subsoil become increasingly sloppy from reworking. However, it keeps the dozer close to dry land while bottom conditions are observed. This pattern is shown in Figure 6-29.

If the original strip is worked back to the limit of the area to be served by the ramp, then widened at the far end, windrows will form at its sides that will allow moving larger loads. The cleared space will not be subject to being crossed by other loads of mud. However, the risk of getting stuck is greater, and if the ramp

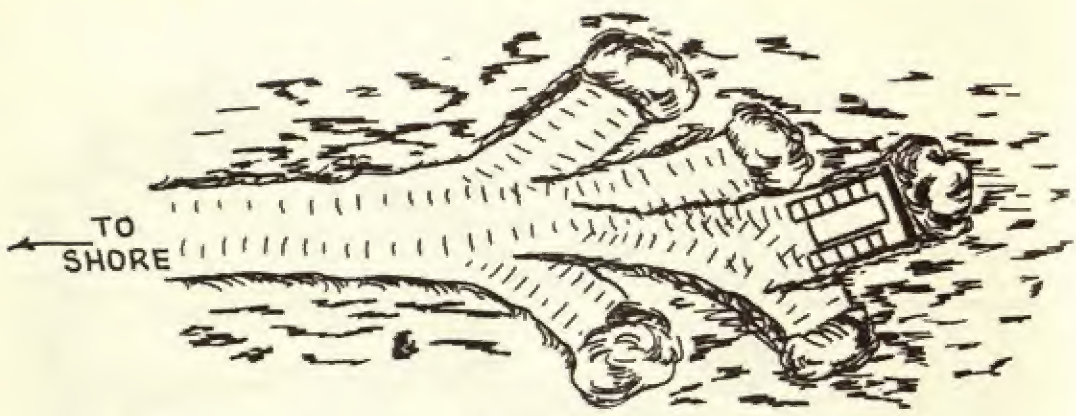


Fig. 6-31. Breaking a path

breaks down and becomes unusable, the material near it, which should have been the shortest and easiest push, will have to be moved to another ramp. Figure 6-30.

The long slot is made in shallow mud by backing away from the ramp. In deeper mud it may be necessary to work away from the ramp, herringbone fashion, before starting to push in, as in 6-31.

Loads brought in at a sharp angle to the ramp are generally dropped temporarily in front of it to avoid the excessive churning of swinging a load.

Dozer and Dragline. Ramp difficulties, or lack of nearby disposal areas, may make dozer cleaning impractical even when the bottom conditions are favorable. In such cases, the dozer may push the mud so that it can be reached by a dragline standing on the shore or the pond bottom, which can pile it on the bank or load it into trucks, as in Figure 6-32.

This method can be rather widely applied and is usually more economical than doing the whole job with the dragline.

Pump. Cleaning by machinery usually mixes some of the mud with so much water that it becomes too thin to be picked up or pushed, but can often be pumped.

A diaphragm pump will handle heavier mud than a centrifugal, but the volume moved is much smaller.

If a water source is nearby, clean water can be pumped into a hose line and the mud stirred up, thinned, and driven to the mud pump or gravity outlet by a stream directed from a nozzle. If patience and man power are sufficient, whole ponds can be cleaned in this manner.

After removal from the pond, the mud may be allowed to flow away from the work area, or to accumulate in natural depressions; it may be held in a settling basin from which it can be dug after it has dried; or it may be placed directly in tight-bodied trucks. The very thin muds which pump most easily are usually the hardest to dispose of. The contractor is liable for mud damage downstream or on adjoining property.

Water Plants. Vegetation growing on the bottom may choke and fill a pond. Deep ponds are not bothered much this way, particularly if they have steep shores.

Many bottom plants, and the microscopic ones that float in the water and give it a dirty appearance, may be killed by doses of copper sulphate. This may be obtained from large hardware stores or from dealers in commercial chemicals. The easiest way to apply it is to put it in a burlap or other loose weave bag, and tow it through the water with a boat, or by swimming or wading.

Two to three pounds to a million gallons of water, applied two or three times a year, should keep a pond clean. If it is allowed to become heavily overgrown, applications of two to three times that amount, at two week intervals, may be required.

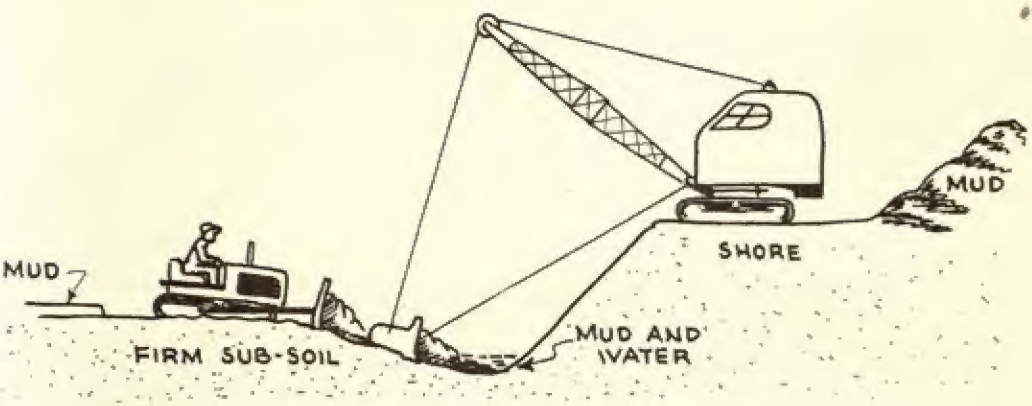


Fig. 6-32. Dozer-dragline team

There is a slight danger that doses heavier than those mentioned might kill a few fish because of decomposing plant matter clogging their gills. Even if no fish are present, heavier doses are seldom economical.

Pond area may be roughly calculated from dimensions found by pacing, or by stadia as in Figure 2-19. Soundings will indicate the depth. Area in square feet times average depth will give cubic feet of water. One cubic foot equals 7.6 gallons.

Copper sulphate cuts down the food supply of fish by reducing the vegetable food that is the basis of all animal life in the pond. Usually a balance can be preserved in which the plants are reduced enough to be unobjectionable but sufficient food is left for a large number of fish.

Bottom plants may also be prevented from growing by adding a general lawn or garden fertilizer to the water. This encourages heavy growth of microscopic plant life, which turns the water brown and cuts off the sunlight necessary for the early growth of the larger plants.

Fertilization of water increases the ability of the pond to support fish by providing more food. However, the brown color makes the water unattractive to swimmers and detracts from the appearance of the pond.

Water weeds that resist copper sulphate can usually be killed by sodium arsenite. This very poisonous chemical is applied to the surface, preferably by orchard type power sprayers in warm clear weather.

From 1 to 4 gallons of the liquid, or 5½ to 21 pounds of the powder, will treat 64,000 cubic feet of water, or a pond 40 × 40 feet, 4 feet deep. The amount used varies with the density of weed growth.

Such proportions are not harmful to fish, except that the decaying weeds use up oxygen. Unless there is a strong inflow, heavy weeds should be treated a section at a time to save the fish from suffocation.

Emergent weeds such as cattails and water-lilies can be killed by a 1.0 percent spray solution of 2,4-D, or kept from spreading by about $\frac{1}{10}$ that strength.

Complete information can be obtained from Fishery Leaflet 344, Department of the Interior, Fish and Wildlife Service.

State fish and game authorities can supply the names of contractors qualified to do this work. Permits from the state, and from the Board of Health may be required for any chemical treatment of ponds.

In small areas weeds can be removed successfully by pulling them out with rakes or by hand.

SWIMMING POOLS

A concrete-lined swimming pool is a special type of artificial pond which is enjoying increasing popularity. It is tremendously more expensive in relation of area

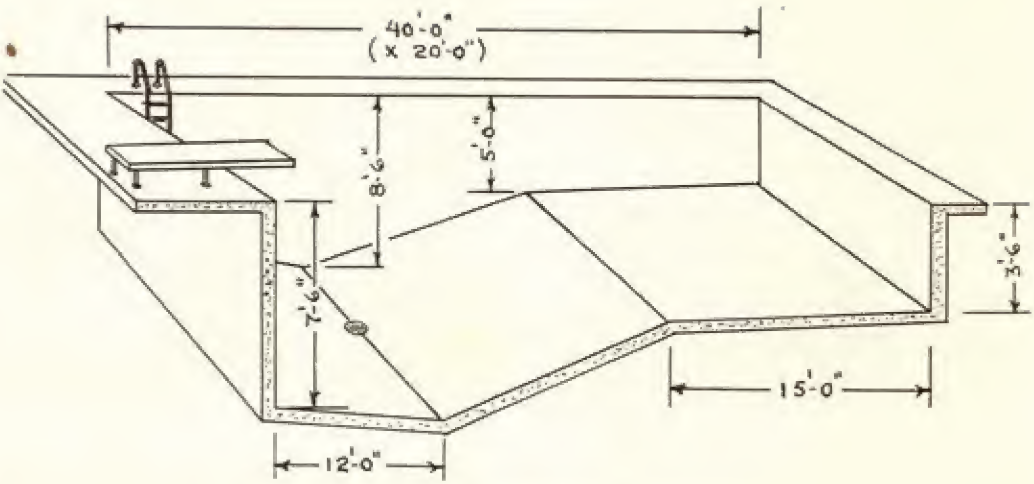


Fig. 6-33. Dimensions, family swimming pool

and volume of water. On the average, it requires more upkeep. However, it is much more flexible in location and is more limited in space requirement. Many persons who have an aversion to mud or water snakes or even just nature will carefully avoid a natural or dug pond, but swim happily in a pool.

A pool should be made of reinforced concrete. Concrete block construction is risky, although it is often successful in well drained soils in frost-free regions. It sometimes ends up with a reinforced concrete wall inside it.

The standard type of pool has vertical walls joined at right angles, and a floor slope which allows diving at one end and wading at the other. A usual dimension for family use is 20 x 40 feet with a maximum depth of nine feet. An excavation is made in about the same manner as for a cellar except that more care is taken in finding firm and uniform footings.

A less common but somewhat more economical pool may be made by digging a hole with irregular shape and sloping banks, setting reinforcing rods on the bottom and sides, and spraying on concrete to make a structure conforming with the irregularities of the excavation. This requires very firm and uniform soil for proper support. Whether the less conspicuous but also less conventional appearance is good or bad is a matter of personal taste.

A pool must be stronger and better supported than a house foundation, because of the variable load of water it must carry. When it is full, it weighs heavily; when empty, it is light enough to float. In fact, ground water and tide have been known to float pools out of position, with little or no damage to their structure but, of course, severe impairment of their usefulness.

It is desirable that a pool be eqipped with a pump and filtering apparatus to remove dust, pollen, and other materials that fall into the water. The attractiveness and the cleanliness of the water are improved, and the frequency of needing to clean the bottom and walls are reduced.

If the capital budget is small, a pool for family use only can be kept usable by frequent addition of new clean water through a garden hose, and draining and scrubbing as often as necessary.

Maintenance includes supplying small amounts of chemicals to kill algae, removal of bottom debris with a suction hose, and occasional draining, cleaning, and painting.

When freezing weather is expected, the pool should be kept full, and logs fastened along the edges and sometimes across the center for protection against ice pressure. Eight foot lengths are convenient.

CHAPTER SEVEN

LANDSCAPING AND AGRICULTURAL GRADING

HOME LANDSCAPING

Landscaping may include the processes of cutting, filling, or grading to change ground contours; retaining or placing adequate topsoil; preserving, moving, or adding vegetation, and planning and installing walls, drives, and game courts.

An important purpose is to produce a pleasing appearance. This may be an end in itself but is usually secondary to the use of the land.

Landscaping is often the final step in jobs which involve earth moving. It is required in connection with highways, particularly of the parkway or thruway type; to improve the appearance of home or business buildings not surrounded closely by other buildings and paved areas; to beautify parks, and to provide them with suitable recreation areas.

Plans should take into account proper drainage, which may include subdrainage.

Landscaping is often done under the personal direction of the landowner or his representative, but may be finished to grade stakes or left largely to the contractor's judgment.

A large part of the annual landscaping bill is for work around homes. Much of this is done during house construction or immediately after its completion, in connection with backfilling around the foundation, disposing of dirt dug for the cellar or footings, and restoring surface drainage.

Such landscaping may include construction of terraces, retaining walls, and driveways, moving or planting of trees and shrubs, and making lawns.

The excavating contractor may perform the entire job or only the heavier parts.

CHOOSING THE SITE

House Elevation. The type of grading close to the house is determined by its elevation relative to the land. The wood sills or trim should be at least four inches above the finished grade of the topsoil. In general, exposure of more than a foot or two of foundation causes a house to look too high for current styles. The ground should slope down away from the house enough to prevent surface water from standing against the wall.

A house may be set high enough so that dirt from the cellar excavation can be used entirely in backfilling and grading up to it. If the floor level is determined in reference to the original grade, the bulk of the piles must be "lost" on the grounds, or trucked away. If one side of the house is level with or cut into an up slope, massive

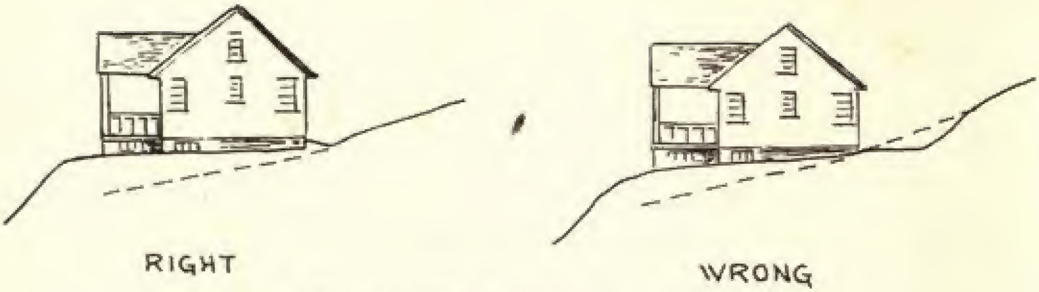


Fig. 7-1. Elevation of house on slope

excavation will be required to give outward drainage. This is costly and will produce an artificial appearance. See Figure 7-1.

Grading is also affected by the extent and type of cellar excavation. A deep, full cellar produces large quantities of fill, while digging for footings and a floor slab may yield little or none. When the house is to have a cellar, is to set low, and is to be built on a plot having a good grade, it will probably be economical to haul away all dirt not required for backfill around the foundation.

Desired depth of the foundation below ground line may be obtained by digging full depth and removing spoil; by putting the cellar floor at the original surface and filling; or by an intermediate method. In general, the most economical way is to cut just enough to provide the necessary amount of fill to build the ground up to the house.

Rock and Water. The presence of rock or water near the surface may make a plot a poor investment, and in any case is important in deciding whether to have a cellar, and the depth to place its floor.

Shallow rock can be found with a probe made of four or five feet of $\frac{5}{16}''$ stainless steel rod, with a sharp point at one end and a handle at the other. This can be pushed down into any but the hardest soils.

However, it will not tell whether resistance is a cobble or ledge. A long sharp crowbar or prybar can be sunk by repeated dropping and turning. If it is stopped by an obstruction, lack of vibration as it strikes indicates a small stone, vibration only near the hole a boulder, and a general jarring, a formation of bedrock.

Vegetation will tell a lot about water conditions. Bush willows and bog or bunch grass must have it wet in the spring at least. Such water-loving plants on a flat indicate swamping conditions. On a slope they show a spring or seepage, and may warn of ledge rock as well.

If rock or a high water table is found on the site or surface drainage is poor, it is often good practice to reduce the depth of excavation and truck in fill.

No fill should interfere with drainage from adjoining property. If the land must be raised, drains should be placed under or around any dam that is formed.

A septic field on low or impervious ground may have to be placed in a filter bed (pervious fill) which may be quite costly.

Hill or Valley. Choice between a hill or valley site may be largely a matter of personal preference. Some people like to look down, most like to look around, but a few enjoy a closed-in feeling. Often, however, these preferences will not be strong enough to outweigh other considerations.

A hill top is almost always well drained, so that the wet cellar difficulties discussed in Chapter 5 will not arise. On the other hand, it is much more likely to have rock close to the surface, so that the expense of cellar digging may be three to six times greater than for dirt excavation.

Ground drainage can be too good. A person wanting to enjoy lawns and gardens will have difficulty with them in dry weather if they are on a heap of sand or gravel. Top-

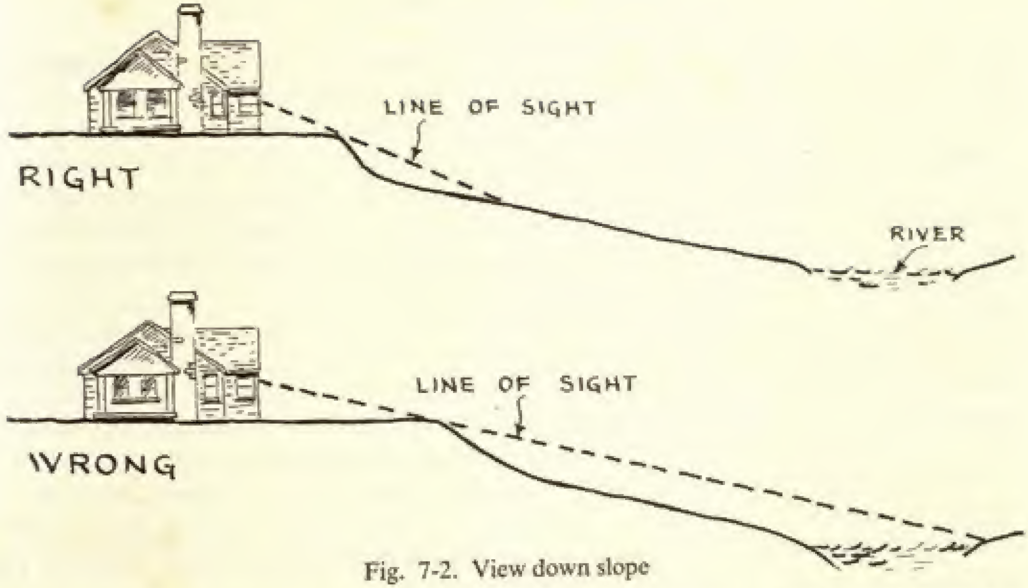


Fig. 7-2. View down slope

soil is likely to be poor, thin, and stony.

A top-of-the-world house gets whatever breeze exists in hot weather, but may get rather too much wind at other times. In icy weather it may be hard to get home up a slippery driveway, but it would take very bad conditions to make it impossible to get out in the morning. Allergic trouble with pollen and molds is usually somewhat reduced.

Building on low ground risks water trouble in the cellar, if any, and the possibility of serious flooding from streams or drains. It limits view to the immediate surroundings, provides a higher average temperature but increases danger of frost damage (cold air flows downhill), reduces effect of cooling breezes in the summer and even more cooling gales in the winter, and usually provides rich and moist soil for lawn and garden.

If at all damp, a low site is dangerous to the health of arthritis and asthma victims.

Slopes may offer any combination of features of high and low land. Special factors to consider are that if the land slopes down to the south it will be warm (or hot), and if down to the notrh it will be cold. Western exposure offers sunsets, which are much more popular than sunrises. Steep slopes make landscaping difficult and expensive, although the final result may be worth it.

Steep driveways are a perpetual nuisance. Elderly people may be prevented from walking and visiting by the necessity of climbing a slope. Severe wet cellar difficulties are rare but not unknown, and some water trouble is common.

View. A house on high ground may be largely deprived of the enjoyment of a fine view by being set too low or too far back from a slope, or by careless grading or planting.

The majority of houses are now the one-story type. When two-story construction is used, the ground floor, particularly the living room and terraces, is the level from which scenery is most often enjoyed. Scenic potentialities should therefore be worked out in reference to a person seated on the ground floor.

A common error is building or failing to remove a high spot which, although lower than the house, blocks the view of nearby down slopes and hollows. See Figure 7-2.

There is often conflict between trees and view which must be decided on a basis of individual preference. In general, ordinary young trees may be quite readily sacrificed while old trees or fine specimens

of younger ones should be preserved if possible. Drastic pruning will often serve the same purpose as removal.

Shade. Shading a house and grounds from full sunlight is desirable, but too heavy shade will cause excessive trouble with rot and mildew, and create unhealthy conditions, particularly for asthma and arthritis sufferers. Such trouble may be reduced by building in the open, by high trimming of branches of existing trees to permit full air circulation, and by use of discretion in planting.

A person buying a plot for its fine trees should be sure that it will not become necessary to remove them in order to build a house.

Noise. If noise from a highway or railroad is of critical importance in determining house location, it should be remembered that it travels chiefly upward, partly because of reflection from the pavement or roadbed. Even hundreds of feet up a hillside will not reduce it substantially if the source remains within sight.

If the river in Figure 7-2 were a noisy highway, the construction which is wrong from a scenic standpoint would become right when noise only is considered. An earth bank is a more effective sound deflector than a hedge or other planting.

Water Well Drilling. A substantial portion of both home and industrial building is in areas not reached by water mains. Most farms depend on ground water for domestic use, and many use it for irrigation also. Factories, theaters, and other large users of water may find that they need a supply in addition to city water. Under such circumstances, the only method of getting a dependable supply of safe water may be to drill for it.

In sandy or gravelly soils surface water outcrops, such as ponds and springs, give a rather good indication of the level and abundance of subsurface water. However, a well should go substantially deeper than this level, both for purity and for protection against unusual dry spells.

Where possible, it is best to get water from rock, or deep down in sandy soil. Danger of contamination is then negligible. Casing is driven down at least far enough to keep surface water and loose soil out of the hole.

Wells are usually located for convenience, on the first try at least, as prediction of underground water may be highly uncertain. This is particularly so when the soil is too shallow to provide safe supplies, and water must be obtained from rock.

Divining rods of various kinds are used in many sections to locate water. In tests these "dip sticks" have shown a somewhat better record than random drilling, but the difference can usually be accounted for by the good judgment of the experienced man who carries it.

The best place for a well for a residence is just outside the foundation line, so that it can be included in a small extension of the cellar or connected by a short pipe, but can still be reached vertically from outside for pulling underground equipment and servicing the underground part of the pump. It is usually drilled and lined (cased) before the cellar is dug.

Placing the well away from the house involves building a rather costly separate pump house, which may offer a landscaping problem and which will have to be connected to the house by water and electric lines. It does have the advantage of freeing the house from the noise of the pump and automatic switch, and the possible nuisance of water from leaks.

A well under the house is very convenient, and lately has become permissible because of improvements in pump design. The flexible plastic pipe and jet pumps, now most commonly used in drilled wells, make it possible to service them in spite of limited headroom.

Distance between sewage septic fields

and wells may be subject to local regulations. Under ordinary circumstances, there is no conflict between having them in the same place if the well is deep, but there is a slight chance that the casing might crack or become disjointed and allow leakage into the water. For this reason, prudence dictates that the well top should be higher than the field, and at least 50 feet away from it.

The spudding or well drill, usually mounted on a truck, is the standard tool for the drilling. When water is encountered, its flow in gallons per minute can be roughly measured by bailing.

A hand pump may be put on a well for use during building construction.

A flow of four gallons per minute is considered adequate for a small residence, but double this is desirable to assure a generous supply. A small water flow can be partly compensated by a large storage tank.

SHAPING THE LAND

Backfilling. In general, it is most satisfactory to backfill around a foundation before the framing of the house is started. This removes the piles of fill that form an obstacle and a hazard during construction, and provides space for entrance and piling of materials.

Backfill against fresh masonry must be done carefully. A heavy dozer should keep farther away from the wall than the diameter of the largest stone found in the fill, to avoid accidental punching of holes. It should not walk on fresh backfill parallel to the wall because if it sinks on the side toward the house it will exert a heavy thrust, and be almost impossible to get out without causing damage.

Foundation backfill is seldom tamped when it is placed, but failure to compact it offers the danger of the loose dirt soaking up enough water during a heavy rain to crush the wall by hydraulic pressure. Good underdrainage around the footings, a proper surface slope away from the house, and compaction of the surface make such a disaster unlikely. Placing floor beams strengthens the foundation.

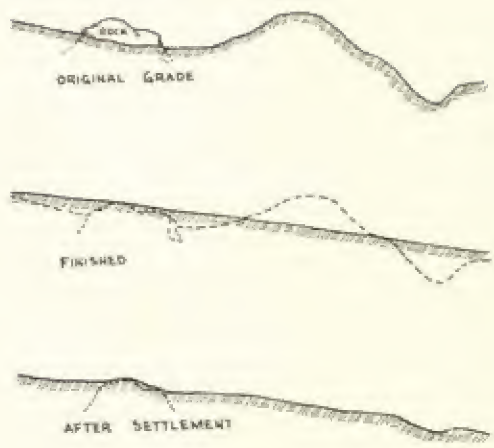


Fig. 7-3. Irregular settlement after grading

A foundation of concrete block is subject to damage even after curing. Unless the fill is wet the weight of the dozer is unlikely to cause damage, but a stone may still be punched through it.

A shovel dozer is the preferred tool for backfilling and grading around a house. Its ability to back and turn with loads, to cross graded ground with a load without excessive damage, and to place dirt exactly where it is needed, enable it to accomplish much more work than a bulldozer of the same size. However, it cannot grade quite as close to a wall because of the overhang of the back of the bucket in dumped position, and the fact that the bucket is little, if any, wider than the tracks.

Grading. Grading may be mostly or entirely a problem of disposing of surplus fill to the best advantage. At other times it will consist of arranging for proper drainage, removing objectionable humps or filling gullies; disposing of stone walls or boulders; reshaping to obtain a desirable view or to avoid an undesirable one, or rearranging contours for better appearance. These operations may produce a surplus of

soil, or may require bringing in hundreds or even thousands of yards.

Soil in trenches and fills should be thoroughly compacted before the fine grading is done. Unfortunately, it is not common practice to attend to this on small jobs, with the result that an originally pleasing appearance degenerates badly in a year or two. Effects are bad when a level or evenly sloping lawn settles into humps and hollows, and are worse when game courts, stone walls, or paved drives are involved. See Figure 7-3.

Trench backfill can be compacted by hand, with air, gasoline, or mechanical hammers, or with electric vibrators. If ample time will elapse before grading, ditches can be loosely filled then puddled by flooding with water. Full shrinkage will not occur until they have dried out, a process which takes a few days with porous soils and weeks with heavy ones. While wet, a puddled ditch is a dangerous trap for machinery.

Septic fields and tanks can be easily damaged by machinery or trucks.

Fills should be compacted by rollers or trucks. If trucks are used, each fill layer (preferably not higher than ten inches) should be thoroughly rolled first empty and then loaded. Running a loaded truck on loose fill puts a severe strain on its power train.

If an area to be filled is cut to an even grade or the high spots broken up first, results of settling will be less damaging than if fill is placed over an irregular surface.

A medium textured fill is more satisfactory for most purposes than either very porous or very heavy soils.

Lawns should not be perfectly flat for any appreciable distance. The maximum slope which it is convenient to mow is about 1 on 6 for long grades, and 1 on 3 for short terraces that are hand cut. Steeper grades may be left in long grass, planted with vines, shrubs, or fixed as rock gardens.

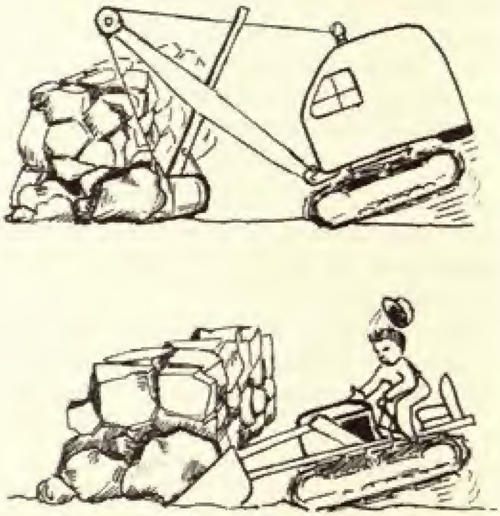


Fig. 7-4. Stone walls may be very solid

Old Walls. In New England and many other sections of the country, utilizing or disposing of old stone walls is a common problem in landscaping. They often contain huge stones which are so buried and bound that they offer a problem to any but the largest machinery. For this reason, and because of the beauty of many of them, it is advisable to leave them in place when possible.

A dozer can move a wall but can seldom rebuild it properly. A shovel or a shovel dozer can dig out such a wall and roughly rebuild it with the bucket, or with the help of chains and a good rock man, reassemble it better than new. The chain work is slow and expensive.

If the wall is to be removed an attempt should be made to sell it. Weathered field stone in small sizes is often in demand. Boulders can occasionally be used in deep fills, stream bank riprap, or breakwater construction. Prices obtained for large stone seldom more than repay the expense of handling.

If there is no market for stone, an attempt should be made to bury it. The bulk can be roughly calculated by measuring the length and the average height and width of

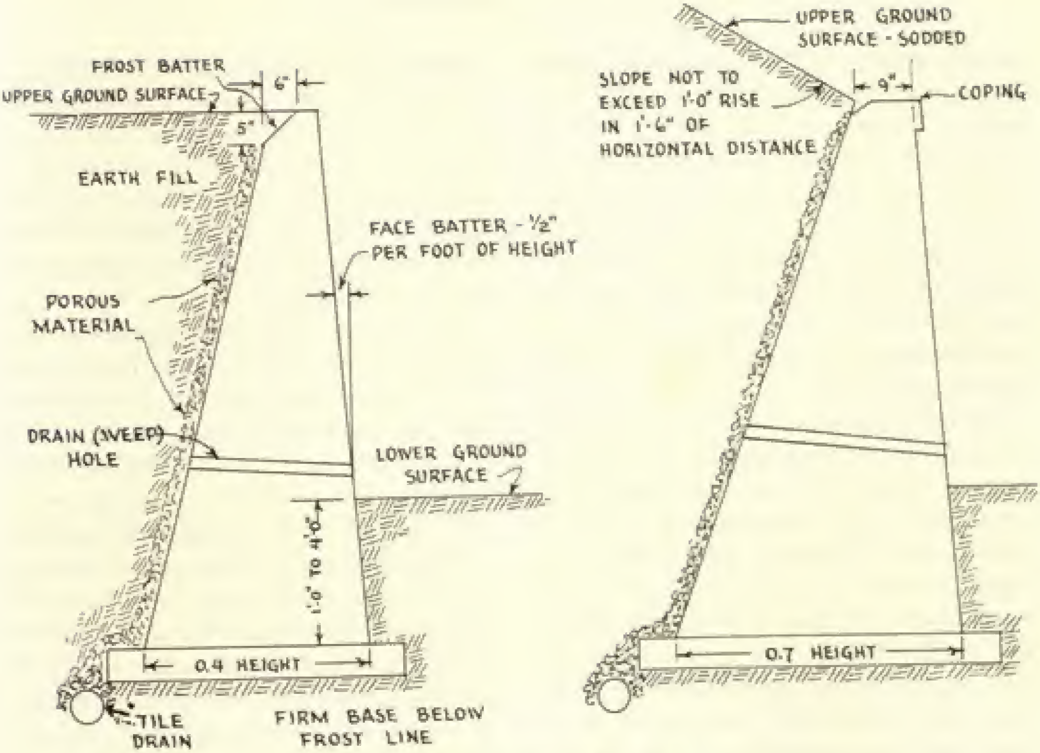


Fig. 7-5. Retaining wall sections

the wall, including the underground part. If no gully or other natural disposal point is available, a hole or holes should be dug to contain somewhat more than the calculated yardage, allowing for a foot or more of fill over the top.

Excavation is done in the same manner as for a cellar. Topsoil should be stripped off the area that is to be dug and regraded. The hole should be deep rather than wide, and might well be dug by a hoe rather than a dozer, if one is on the job. A hoe may dig a trench close along the wall, followed immediately by a dozer pushing the stones into it and regrading.

A hoe is often more efficient than a dozer at breaking up a stubborn wall, as it can work out one stone at a time. However, it cannot transport the stone readily.

The rocks can be trucked away if burial is impractical because of shallow soil, trees, or landscaping. A shovel dozer, a dipper stick, or a big clamshell can break up the wall and load it. Trucks should preferably have bodies built to carry rock, or be so old and beat-up that damage will not matter.

Loading a wall is slow work. Even small stones may be hard to dig out when in groups, and big ones are hard to get securely in the bucket. Production in yards-per-hour may be pitifully low.

Retaining Walls. Masonry walls are frequently used to separate different ground levels. They may be required where the slope is too steep for earth, or used largely for the sake of appearance. In the first case, the wall may make up only part of the required rise, and an earth slope is continued from its top. Such walls must be strong and well founded if they are to give good service. They are subject to very heavy pressure from the dirt behind them, particularly if it slopes up from the top of the wall, and if it becomes saturated. Freezing will cause a push against the top of the wall and disruptive forces inside it. Tree roots can act to lift and overturn it.

Some cross-sections of retaining walls are shown in Figure 7-5. The foundation must be adequate or the wall will fail. If the ground under it is unstable because of its nature, recent placement without proper compaction, or frost heaving, the wall will break up or lean outward. It is therefore essential to found it below frost level on firm soil or rock. If the quality of the soil is questionable, a wide concrete footing slab may be poured.

The thickness and strength of masonry required for a retaining wall are commonly underestimated. Results of under-strength construction are sometimes satisfactory, but often not. For safety, wall thickness at any point should be between one-third and two-thirds of the height of the wall above that point, and the top should be six to nine inches thick. Minimum thickness is safe when reinforced concrete is used, when height is moderate, and the retained soil well drained and stable.

Maximum thickness is required when a steep slope rises from the rear of the wall, and when the ground is very unstable. Other considerations are the strength of the masonry. Reinforced concrete is the strongest used. Plain poured concrete is considered stronger than concrete block, brick, or mortared stone. Dry stone walls have little resistance against thrust and should be kept low.

The push from dirt behind the wall can be minimized by keeping it well drained. A layer of gravel or other porous material should be placed along the rear face of the wall. A tile drain should be placed beneath the foundation, and there should also be "weep" holes through the wall itself.

Ground expands when the water in it freezes, and the surface slab formed in this manner can exert a considerable thrust. A slope or batter at the rear corner will deflect this pressure upward so the slab will slide on the wall instead of pushing it.

A vertical wall often has an appearance of overhanging. A backward lean or batter of one-half inch for each foot of height will counteract this. Such batter can be increased to any desired slope with some increase in stability. A face slope in a dry masonry wall may permit outward movement for some years before it becomes vertical or overhanging.

Drainage. It is desirable that all areas be provided with sufficient surface slopes, proper subdrainage, or both, so that water will not stand anywhere, and the ground will dry and firm rapidly after saturation. Particular care may be required to subdrain any soil touching cellar walls or floor.

When the soil is porous sand or gravel and the water table is low, drainage is usually automatic and mistakes in gradient will show only briefly during rains. Impervious soils, however, demand care in shaping so that they will drain completely, not only when the job is completed but after settlement of fills.

If pervious fill is placed on a relatively impervious native soil, the lower surface should be shaped to drain, to avoid trapping underground water in pockets. If the native soil to be buried is pervious it need not be graded for drainage, regardless of the type of fill, although shaping to avoid uneven depth of fill is still advisable.

Where areas are large, rain water flowing on the surface may constitute a serious nuisance even if it does not erode the ground. At a price, such water can be caught in catch basins, then removed through underground pipes. Because of the expense of such an installation it is best to have it designed by someone familiar with the work. If this is not possible, pipe size should be figured in the same manner as culvert capacity, according to the maps and tables in Chapter 5. Sometimes undersize pipe is used for economy, on the basis that occasional overflow along the surface under extreme conditions will do no great harm. However, eight inch pipe is the smallest

that should be used with such catch basins.

If land tile is used, it will also function as a subdrain. However, care must be taken not to allow more surface water to enter it than it can easily handle, as the hydraulic pressure resulting from water standing in or over the inlets may force channels outside the tile, which will undermine or misalign them, with resultant impairment or destruction. If the important problem is surface water, concrete pipe or sewer tile with mortared joints is preferable.

All inlets should be protected with gratings firmly set in masonry. Lack of these may permit entrance of large objects or masses of material which will plug the drain. Gratings are usually larger in area than their pipe, to allow for partial clogging with leaves. The vertical or steeply sloped pipes up to the catch basin should have tight joints.

If backfill is not tamped in the trench made for the drain, it may settle and leave the grating standing up above the sod. This is unsightly, makes it vulnerable to breakage, and interferes with reception of water.

If a garage is below ground level, a catchbasin in the driveway just outside it is necessary. This drain MUST be adequate, as its failure in a heavy storm will flood the garage and perhaps the cellar.

Gutter drainage to dry wells or tile is discussed in Chapter 5 under Cellar Drainage.

Subdrainage. Land tile subdrains may be installed under lawns and gardens to correct saturated or oozing conditions, to speed up drying after rain, or to provide better growth conditions for plants. Because of expense, they are generally limited to "show" sections or game courts.

The same techniques described for agricultural drainage are employed, except that the interval between tile lines is often much smaller, spacing as close as ten feet sometimes being used under tennis courts.

Subdrains may be tied in with the tiling around the cellar and with catch basin systems for surface runoff. They should drain to low areas when possible, as opening into storm water drains expose them to damage from backed-up flood water.

FINISHING OFF

Topsoil. Topsoil which has been salvaged in advance of digging may be spread as soon as the fill is graded off, or left piled until the house is finished. Immediate spreading provides a cleaner appearance which is of particular value to houses built for sale, but the topsoil is liable to become mixed with various sorts of waste, and to be severely packed by supply trucks.

The two-ton "toy" shovel dozer or bulldozer is the best unit for spreading as it is so light that it leaves average topsoil in condition to be finished off by hand, where heavier machines compress it so that machine tillage is required. It also can maneuver among trees, retaining walls, and other obstacles with less danger of damage and far less loss of time than larger dozers. It can work over the average septic tank or field, and can often do a complicated job more quickly than its big brothers.

An excellent team for residential grading is a shovel dozer as big as the traffic can bear for the long and heavy pushes and carries, and a two-ton to distribute and smooth off the material.

A light farm tractor with a pusher blade can do auxiliary or light grading.

Freshly spread topsoil or undisturbed field sod which is to be reworked into lawn is often loosened up with a rotary tiller. This machine leaves it soft and easy to work, and if the topsoil is thin will increase its usefulness by mixing in some subsoil.

It is not possible to state a general rule for the amount of topsoil needed around a house. Good topsoil has three important characteristics: it contains humus which absorbs water and doles it out to plants in dry weather, it contains a supply of available fertilizer, and it has a grain size and

arrangement that is favorable to plants.

A lawn made with poor or too thin topsoil may be persuaded to grow vigorously by proper fertilizing. However, it will tend to burn out during dry spells unless it is shaded. It will dry out more readily if it is over gravel or sand subsoil than over heavier soil. The minimum topsoil depth for a lawn under most conditions is two inches, and four inches is safer. However, benefits are obtained from greater depths, and it is common practice to use up whatever piles are around. If the original soil was thin, or had been lost, more must be trucked in.

Gardens, flower beds, and shrubs like to have about eight inches, and depths up to two feet are recommended for some species.

If peat (humus) is obtainable locally at a low price, it may be spread on subsoil and mixed in by hand or machinery. With the addition of lime and fertilizer it may serve well as topsoil and might be much cheaper.

Converting Field to Lawn. The original lawn made around a new house may be partly or wholly at the grade of an existing field supporting a growth of mixed grass, wild flowers, and weeds. The standard way to make a lawn is to use a rotary tiller or a plow and a harrow to turn in the existing growth, and pulverize the soil for planting of grass seed. It is usually good practice to bury the old vegetation several weeks before planting. Decay of vegetable residues often temporarily deprives the soil of nitrogen to such an extent that the new crop cannot obtain enough for a start. Also, sprouts from roots of undesirable plants can be readily destroyed as they appear on bare ground, and can be reduced or eliminated before planting.

A less expensive method, which is usually satisfactory, is to pull out any brush, then mow the field repeatedly. It may be reduced in one operation from field length to lawn length, then kept short, but better results are apt to be obtained from starting with a high cut as if for hay, and progressively trimming shorter.

The effect of the cutting is to kill or place at a disadvantage plants that prefer to grow tall, and to encourage those which are not damaged by mowing. Most fields contain enough lawn-type grass and clover to take over the whole area within a year when encouraged by repeated cutting.

A similar effect may be obtained by moderate driving and parking of cars and trucks on the field.

Field surface may be too rough for a lawn. Large inequalities may have to be cut or filled. Smaller ones can be rolled down, filled with dirt or both.

A power lawnmower having heavy steel or rubber rolls will tend to flatten ground. Its effect is quite marked when inequalities are small and choppy and the soil is soft, and becomes negligible as the ground bakes in the summer.

A steel wheel roller, weighing from three to five tons, of the type used in driveway construction and blacktop patching is a very effective lawn flattener, but must be used when soil is in the right condition. If it is too soft, it will make ridges, and probably get stuck. Heavy wet soils may pack so hard as to discourage growth. If the ground is too hard, it will be ineffective. Heavier rollers are sometimes used, but the expense of transporting them and the danger of sticking them is greater.

Hollows may also be filled with topsoil. This may be applied in layers a quarter to half an inch thick so that grass will grow up through them, or the fill made to the level of the surroundings in one lift, then new seed planted where necessary. Sometimes the seed is mixed with the topsoil prior to placing it.

Fills of more than an inch or two on bare ground and any fill over grass tend to settle noticeably so that the work will require

doing over, although with less material, the following year. Over-filling enough to compensate for this settlement requires expert judgment. Firm tamping is sure to reduce this difficulty and may eliminate it, but might make it difficult for existing grass to push up through the new soil.

Planting Grass. Soil should be loosened and smoothed before planting. If the area is too large for hand digging and raking, a rotary tiller of appropriate size is the preferred tool. A plow and a disc harrow, or a harrow only, followed by dragging with a plank will often do a good job. Fertilizer, lime, manure, peat moss, or other soil-enriching materials are best mixed in by hand or machinery. If the area is large, a spike tooth harrow can be used for both smoothing over the ground and covering the seed.

After the machinery is finished, the ground is hand raked. This looks simple but is not. A certain knack is required to get a smooth surface.

Soil acidity can be tested with litmus paper and color scales that are obtainable at garden supply and drug stores. Most lawn grasses like a pH 6. If the soil is pH 5, about 75 pounds of ground limestone should be added to each 1000 square feet. A pH of 4 will call for 100 to 200 pounds for the same area.

Slaked or hydrated lime has a higher calcium content, 100 pounds of it being equivalent to about 135 pounds of ground limestone. Quicklime is still more concentrated, but is inconvenient and dangerous to handle.

It is good practice to add some fertilizer, but the amount varies widely with circumstances and individual judgment. If vegetation has been mixed into the soil within the last two or three weeks, either on the spot or at the source from which it is being hauled, some nitrogen fertilizer must be added, to make up for that borrowed by the decay processes. In general, an addition of a moderate amount of general fertilizer is cheap insurance for the work and expense invested in preparing and planting the lawn.

Any of the lawn seed mixtures are good, and the differences can be explained by the store selling them. A mixture should almost always be used instead of a single kind, as each variety has its own special and often obscure likes and dislikes in soil conditions. If several kinds are planted, there is a good chance one of them will like the circumstances, and its vigorous growth will compensate for any sulking by other varieties.

Seed scattered on the ground surface in very early spring may be worked underground by freezing and thawing so that no effort is required to cover. Seed lying on the surface will sprout and take root successfully during a long wet spell, but hot sun at the wrong time may kill a large part of it. The safest procedure is to rake the ground after spreading seed. This will bury most of it, and recommended applications of seed make an ample allowance for that left exposed.

The grass will come up faster and better if the ground is rolled lightly after seeding. This may be done with a muscle-powered lawn roller, a hand tamper, a power lawn mower of the roller type, or the smallest size of steel wheel gasoline roller. If the job is a rough one, driving a car or empty truck back and forth on it will give good results.

Erosion. A sloping lawn is vulnerable to severe damage from flowing water from the time the topsoil is spread until the grass has made a good root growth. The probability of such damage should be figured into cost estimates by both the owner and the contractor.

Danger of erosion can be reduced by mixing straw or lawn clippings into the surface. This necessitates a heavy addition of nitrogen fertilizer, and makes it harder to cover the seed.

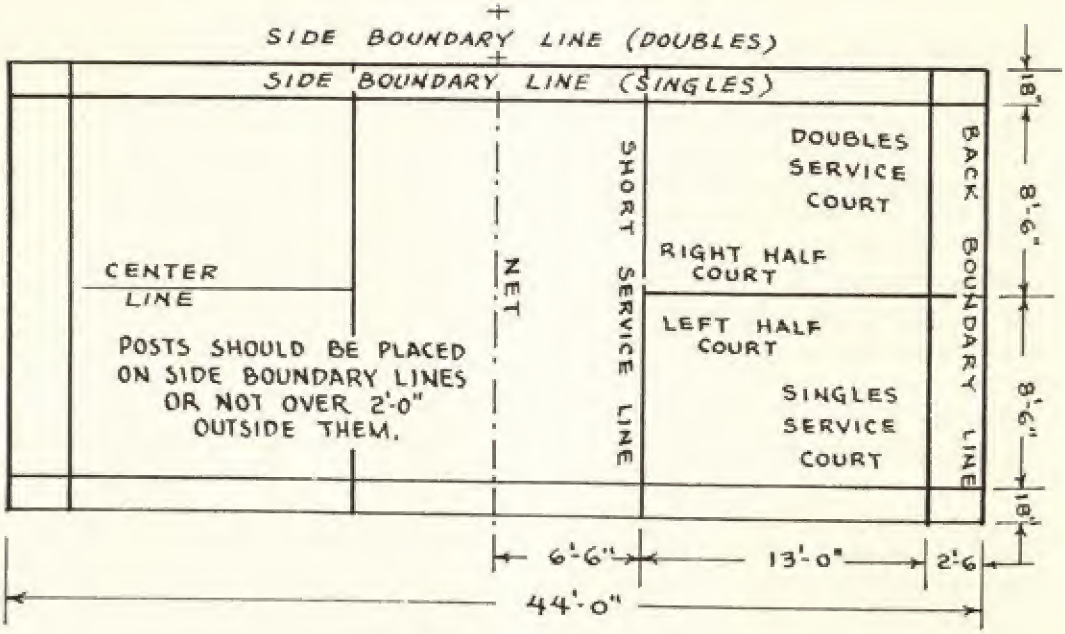


Fig. 7-6. Badminton court

It is sometimes possible to divert drainage into other areas. One section may be fixed up and seeded first, and water routed through the part which is only rough graded. After grass is firmly established, drainage may be shifted to go over it, so the rough area can be smoothed and planted.

Occasionally, it is possible to install temporary pipes or flumes to carry rain water while grass is getting a grip.

Sod. Drainageways and steep slopes can be protected with sod. This is cut out of existing lawns or mowed fields by means of hand tools or a tractor-towed sod cutter, laid on freshly loosened and smoothed topsoil and tamped into firm contact. It is sometimes fastened in place by driving pegs or thin stakes, or by pegging chickenwire firmly over the whole area.

Sod may be cut in strips 12 or 15 inches wide and 6 to 10 feet long or in squares or rectangles of any convenient size. A depth of 1½ inches usually suffices to get practically all the roots.

It is essential that newly placed sod be thoroughly watered and tamped to establish its contact with the ground. It should be watered as necessary until it shows that it can take care of itself.

Home Games. If a house plot has sufficient area, the owner may wish some kind of a play court included in the landscaping plans. Tennis, badminton, and croquet are among the games in most common demand.

Tennis and badminton courts may have the standard dimensions shown in Figure 7-6 and 7-7 or may be smaller or of some different layout, to conform to restricted space, local custom, or individual preference.

Grass blends in best with general landscaping, but to give satisfactory results it must be well fertilized, protected from beetle grubs and burrowing animals, and frequently cut and rolled. Even with the best of care, it will wear bare in spots which have too frequent use.

Clay, and various special materials which give a similar surface, provide the preferred topping for tennis courts. However, they require excessive maintenance in weeding, scraping, lining, rolling, and add-

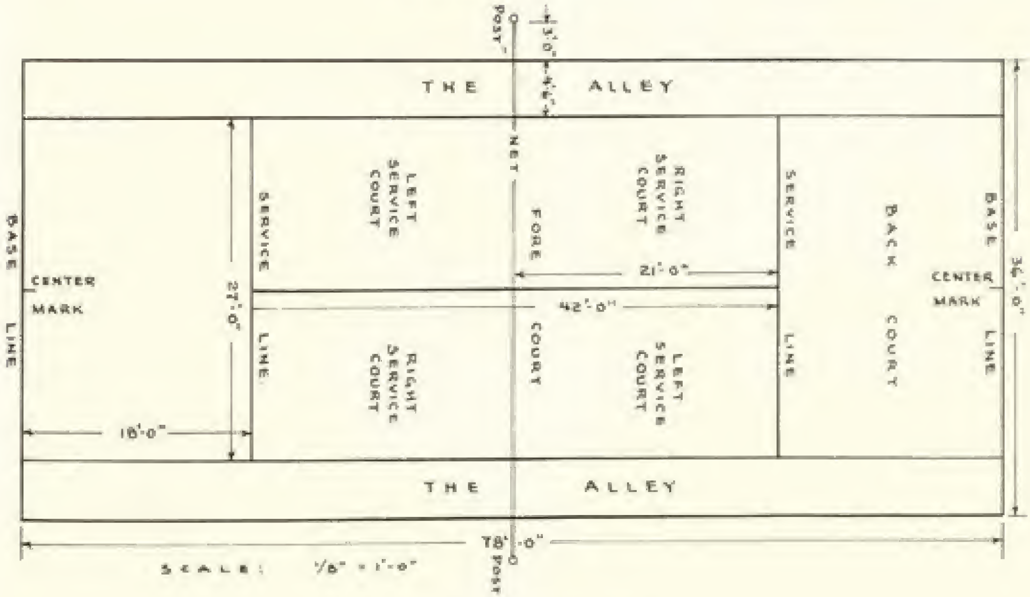


Fig. 7-7. Tennis court

ing of fresh material. Many of them cannot be played for some time after a rain. This last characteristic will vary with the type and condition of surface and efficiency of subdrainage. Idle clay courts require much more maintenance than well played ones. A good bituminous court is most satisfactory for occasional use. It should have a base course of crushed rock or good bank gravel.

The playing surface should be nearly level. If the topsoil is porous, and subdrainage is good, it may be possible to have it exactly so. More often it is better to have a slight slope, of ¼ to ½ percent to a side or corner. Grades should be set by instrument. Particular care must be taken to roll or tamp any fresh fills to avoid an uneven surface after settlement.

Even when surface drainage is provided, subdrainage is desirable to provide quicker drying and earlier usability after a rain. However, too good drainage, such as through a coarse gravel fill, might cause burning out of lawn in dry summers unless about eight inches of topsoil rich in humus is placed.

Croquet is less rigid in its requirements. Two layouts are shown. The first, Figure 7-8 is the professional type, which is supposed to be on practically level ground. The other arrangement can be varied in distances to suit the available space and preferences of the players, and can be played on sloping or irregular ground. In each case, grass is the preferred surfacing.

A satisfactory court layout may be endangered by pulling the wickets to mow the grass. Replacements are seldom in exactly the same place, unless markers are used. The best markers are 2 x 2 redwood or locust stakes about 18 inches long, sharpened at the bottom and drilled at the top with sockets which provide a snug fit for the wicket wire. These are hammered flush with the ground, and serve both as guides in placing wickets and as braces to hold them upright. Spools can be used in the same manner, but are less satisfactory and usually have to be replaced every year.

TREE PROTECTION AND REMOVAL

Trees are liable to destruction or damage from various causes during construction

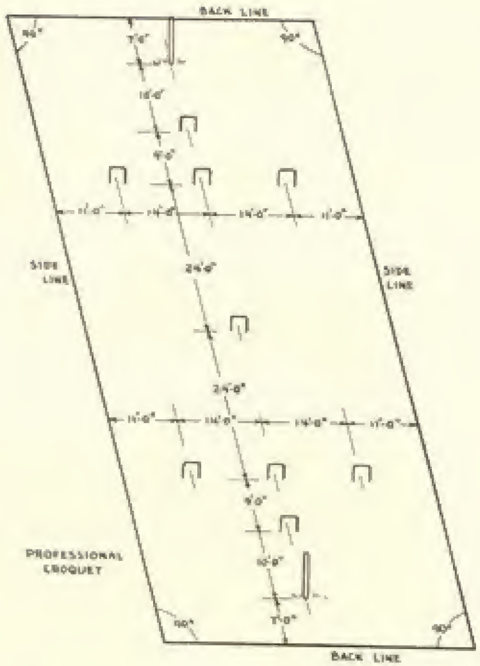


Fig. 7-8. Professional croquet court

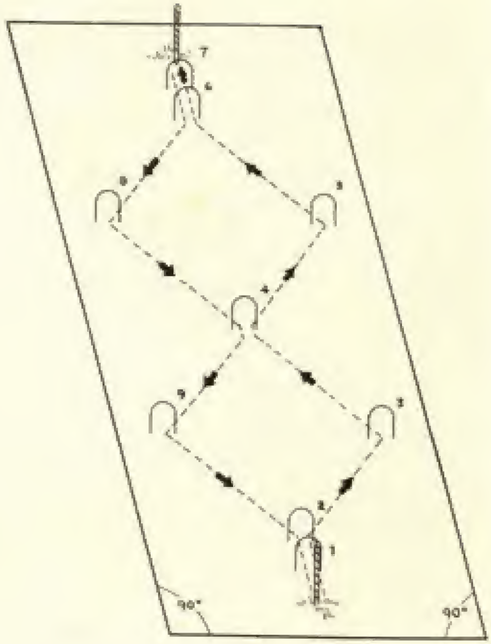


Fig. 7-9. Croquet court, home style

work. Trunks or branches may be broken or scraped by accidental contact with machines; roots may be dug away by ditching or lowering of grade, lessening the tree's ability to obtain food and water and rendering it more vulnerable to uprooting by wind; its trunk may die because of dirt piled around it, or its roots may be drowned or suffocated by placing of fill.

In general, the larger and more valuable trees are less subject to fatal damage from collisions, although the scars they do get heal more slowly; but they are much more likely to die from root cutting or suffocating than younger and more adaptable specimens.

Bark Damage. Trees can be partly or wholly protected from collisions by wrapping with burlap or other cloth, and tying thin wood strips around the trunks and any particularly exposed branches. If used for anchors in pulling out machinery, trunks must have very heavy padding and thick wood pieces between the bark and the chain, and the chain loop should be fastened with a grab hook, bolt, or knot that will not slide. The choker effect obtained from round hooks or rings can readily crush bark and wood all around a tree so that it will be fatally injured.

If a tree is girdled by removing even a narrow ring of bark around the whole trunk, it is supposed to die. However, if the sapwood is not injured and the damage is kept shaded so that the wood will not dry out, young and vigorous trees may repair the cut by growing several inches of callus and new bark across the injury from top and bottom.

If the gap is wide, a skillful worker may be able to graft strips of bark across the injury. If circulation is established through these, they will serve to keep the tree alive and they will widen out so that the damage may heal over entirely.

Scars on trunks or branches should be promptly covered with black tree paint. This protects the tree from fungus and reduces the owner's annoyance about the damage.

Ditching. Ditching on one side of a tree ordinarily does not injure it severely. However, it is best to keep the cut as far from the trunk as possible, thus reducing the number of roots lost, minimizing the danger of tearing the trunk, and making the digging easier.

If a hoe or dozer digs within two trunk diameters of the tree, the roots should be uncovered, and then cut by hand to avoid danger of splitting the trunk while tearing them up.

A close cut weakens the tree's resistance against a wind that tends to tip it away from the ditch. If uprooting in that direction would cause it to fall on a building or across a highway, a tree expert should be consulted about the advisability of providing cable support, Figure 7-10, or removing some of the upper branches.

Burial. A tree's reaction to having its trunk buried varies with its species, health, and nature of the dirt. Burial is fatal to the majority if the fill is deep enough or of such a nature that it will smother the bark and support organisms which will destroy it.

The fill also changes the air and water content of the topsoil and subsoil around the roots. Such changes may damage or kill the roots directly, or indirectly by changing the nature of the soil population.

The best defense a tree can muster is to put out new roots near the surface. The willow does this automatically, but the majority of temperate zone trees do it with difficulty or not at all.

Trunk damage can be avoided by building a stone wall around the tree on the original ground, at a sufficient distance to allow free air circulation. See Figure 7-11. The space inside is called the well. Sometimes the fill is made and part of it dug away by hand to make space for the wall. Or the wall may be built first, and the dirt placed around it.

The first method is expensive and offers some danger of damaging the tree with the digging tools. The second is subject to the danger of knocking over the wall while placing fill, or accidentally spilling dirt over it that will fill up the well.

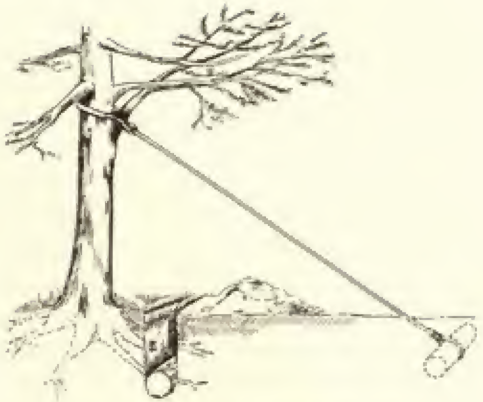


Fig. 7-10. Temporary tree brace

In general, the most satisfactory technique is to build the wall first, and fill the well with easily removed material such as stones, wood scrap, or crumpled newspaper. Such items will prevent any appreciable amount of dirt from entering the hole, and are easily taken out when grading is complete.

Sometimes pebbles or crushed stone collars are used to avoid unsightly or dangerous holes. These will usually allow sufficient air circulation when new but are likely to plug up with dirt.

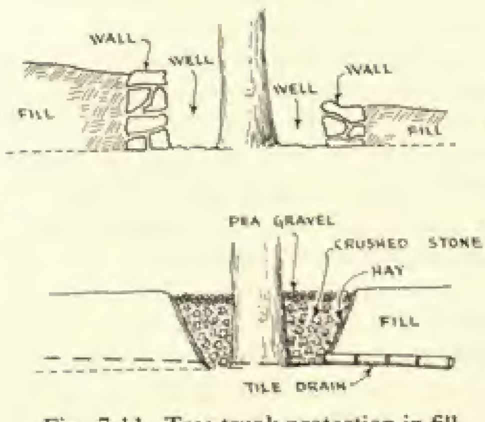


Fig. 7-11. Tree trunk protection in fill

The fill should be pervious enough so that water will not stand in it and in the holes. Tile may be laid to drain the tree wells, but a saturated fill is liable to kill the roots anyhow.

Root protection is more complex and the results less certain. Land tile is laid on the old surface of the ground or slightly below it, with lines three to six feet apart. A four to six inch blanket of crushed stone is laid over the area and covered with hay. Pipe openings at each end of the fill or into wells should allow enough air circulation to preserve favorable conditions long enough to enable the tree to adjust to the changing conditions. Wire mesh must be placed across openings to keep animals out.

If it is not economically feasible to take these precautions, the fill should be made of clean bank gravel or coarse sand. Trees may survive heavy additions of such open textured material.

Removal. Landscaping work may involve removal of trees. If they are to be destroyed the job resembles the land clearing described in another chapter, except that interference from buildings, wires, valuable trees, and other obstacles is much more common.

If the ground is to be filled, trees may be cut as nearly flush with the ground as possible. This may also be done if the grade is not to be changed and the presence of the stump is considered less objectionable than the cost of removing it.

If the grade is to be cut, stumps must be uprooted. Trees may be pushed over by a dozer or pulled down by a winch and then cut up, or may be sawed or chopped down and the stumps removed afterward. A deep soil cut allows undermining of stumps and easier digging out.

Uprooting the whole tree requires a machine of sufficient power to handle it, a clear space for it to fall, and working room for the machine. The trunk may split or be placed under such tension that it will be difficult to saw. Direction of fall can be rather closely controlled.

When a tree is cut it may be harder to control, the trunk should be intact and easier to saw, and the stump will be more difficult to remove, particularly if cut low.

A dozer or shovel can knock out stumps within its size range, and dig out larger or tougher ones where space permits. Winches can be stepped up with blocks to almost any desired power, provided anchors are available. Stumps can be split, loosened, or blown out of the ground by dynamite, but controlling or covering the blasts may be difficult.

Damage to Property. Property may be damaged by falling trees. It is often wise to measure them before felling to see if they have clearance. This can be most conveniently done on a sunny day by setting a vertical stake, measuring it, its shadow, and the tree's shadow. See Figure 7-12. The proportion between the stick's shadow length and its height are used to figure the height of the tree from the length of its shadow. For example, if a four-foot stick casts a three-foot shadow and the tree shadow is sixty feet, the tree height is eighty feet and it will reach that distance when it is down.

A "false shadow" may be cast by a projecting branch so as to exaggerate the tree height. True readings can be taken only from a shadow of the top.

It is often necessary to take trees down in sections, starting at the top. This is a job for specialists.

When a tree or stump is uprooted near a curbing or other masonry, it is apt to pull it up or break it. This damage may be avoided by hand digging and cutting the roots on that side and pulling away from it, but it is often cheaper to break and then repair the structure.

Direction of Fall. Unless a tree is badly out of balance its direction of fall may be controlled by expert sawing and wedging, or by a line pulling it in the right direction.

The line should be fastened high, particularly if its power is weak. Hand pull is not effective for large trees.

Trucks or cars can be used for line pull, but the line may raise their wheels until they have a little traction. They may also stall at the critical moment. A way to use them is to put maximum tension on the line while the tree is still sound and block the wheels to prevent rolling back.

A taut line decreases the effort necessary to saw or cut on the far side of the tree, but makes splitting of the trunk more likely.

A tree pulled by a line will start its fall in that direction, but will usually fall rapidly enough to slacken the line, after which it might veer to either side.

Any machine used for pulling over a tree should be out of its reach. The line may be passed through a pulley block or around a grooved stump to permit the machine to be off to the side.

PLANTING

Selection of Trees and Shrubs. A new house standing entirely in the open often presents a bare and unattractive appearance which can be relieved by proper planting. Selection of suitable sizes and varieties may offer a knotty problem about which the grading contractor may be asked to offer suggestions.

If enough bushes and trees are placed to completely relieve the bare appearance, the house is liable to disappear into a jungle within a few years. This danger can be lessened by selecting plants which are slow growing or which respond well to suppressive pruning. Even if these precautions are taken, the householder should resign himself to the periodic necessity of cutting, transplanting, or selling some of his prized vegetation in order to prevent crowding and to preserve view and healthful conditions.

Cost of planting increases spectacularly with the size of the units. As an example, in

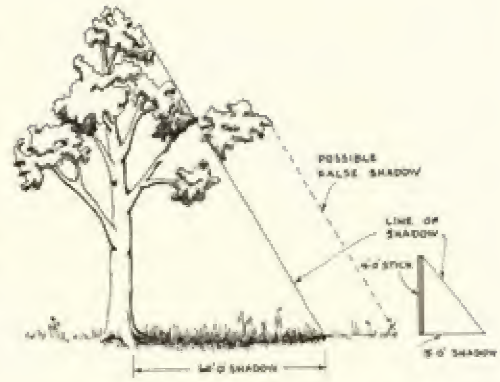


Fig. 7-12. Measuring tree height

one locality white pines five feet high can be purchased growing in the field for a dollar each, or in nurseries for two or three dollars. Anyone with a strong back, a sharp shovel, and the use of a station wagon or convertible can transplant them himself. In the same area, white pines thirty feet high cost about fifty dollars in the ground, and transplanting costs range upward from three hundred dollars.

Occasionally a nursery or farm with a surplus of large size trees will sell them at bargain rates. Because of the high cost of handling them, they are still very expensive by the time they are set in place.

In most areas, a wide variety of trees and shrubs can be obtained and grown, and individual preference and price govern selection. Attention should be paid to the local prevalence of diseases or insects which may mar or kill the plant. Poplars and willows, which are desirable because of very rapid growth, should not be planted near tile drains as they have a disagreeable habit of filling them with roots.

If desirable plants are growing elsewhere on the property, or are available in the vicinity, the contractor may use his men and machinery in transplanting, by methods to be outlined later. However, he should not guarantee that they will survive as there are many factors of soil type, drainage, and pests that may kill them even

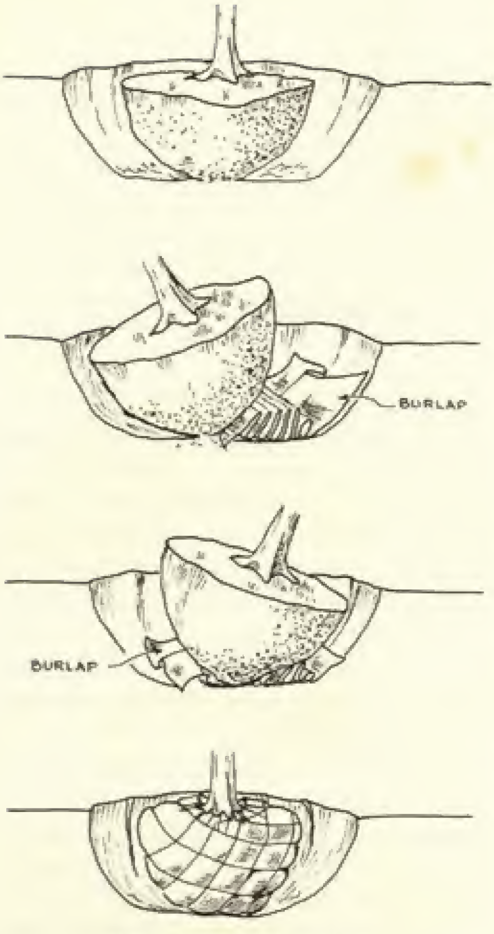


Fig. 7-13. Balling a tree

if he handles them skillfully and which may not be obvious even to a specialist.

Transplanting. Transplanting trees is a specialty best left to nurserymen. However, they may not be available when required so that the grading contractor may have to do the work to get them out of the way.

Very small trees may be dug around with a spade and pried out. If the ball of earth attached to the roots hangs together, the tree may be carried to the planting space with one hand under the ball, the other on the stem. If the soil tends to fall away, it may be tied with burlap or shaken off and the roots covered with damp material until planted.

The very fine root hairs are vital to the life of a tree and they are quickly destroyed by drying. Either sun or wind can kill them in a few minutes, or sometimes even seconds of exposure. Transplanting is best done on cloudy days with little wind, or in rain or fog.

Somewhat larger trees are handled as in Figure 7-13. A trench is dug around the tree, about four to six inches out for each inch of trunk diameter. Roots are cut off flush with the inner wall of the trench. Below the roots, which are usually shallow, the ball is undercut until the tree can be pushed over. A piece of burlap is folded accordion-fashion and tucked under the raised side of the ball. The tree is then leaned the opposite way, the burlap is pulled through under the ball and used to wrap it. The cloth is tied in place with heavy twine or soft rope and is planted with the tree.

If the tree is too heavy to lift, it is dug around and undercut in the same manner. It is pulled over by a winch or block and fall. A square wood platform, with a ring or other fastening for a tow line, is placed under the raised side and pleated burlap over that.

The ball is then rocked back onto the platform and wrapped with the burlap. One side of the trench wall is beveled off, skids are placed, and a tow line fastened to the platform and the ball. They may be dragged to a nearby destination, or winched up on a truck or trailer for a longer move. Fast transportation should be avoided because of the "burning" effect of wind on the leaves.

Care must be taken to protect the bark against injury from attaching lines. The trunk or branch should be wrapped with burlap or other cloth, and flat sticks placed between that and the line. The line loop should not be a choker—that is, it should not tighten up under tension.

Branches which interfere with digging

are tied up, or in toward the trunk, with soft rope.

In the new location dirt should be tamped firmly around the roots or ball and the ground thoroughly soaked. The dirt should come to the same height on the trunk as before, as the above-ground bark may rot if buried. If in doubt about the proper level, it is better to place the dirt too low rather than too high.

The transplant may require bracing to keep it upright. Lines, from three to six in number, are anchored to stakes driven firmly into the ground. They may be rope, wire, or cable. Chafing of the tree bark is prevented by wrapping it and passing the line through rubber hose at the point of contact.

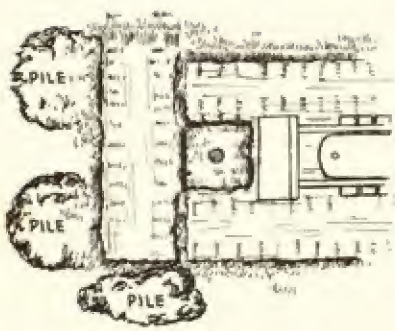
If a tree is transplanted from a shady to a sunny spot, or suddenly exposed to sunlight by the removal of surrounding trees, the trunk and larger limbs should be wrapped to prevent sunburn or sunscald.

Trees and shrubs make most vigorous growth in a deep, rich topsoil. It is good practice to dig planting holes oversize to provide space for putting extra topsoil. This may be enriched by mixing with a little manure or fertilizer, but not enough to injure the roots.

If the planting is in a field where there is competition with other plants, the ground around it may be closely covered with scrap wood or stones. These will not interfere with the tree and will discourage other growth.

Transplanting by Machinery. Trees and shrubs of small to moderate size may often be dug efficiently by machinery.

A bulldozer can cut trenches around the tree and push it and the remaining block of earth onto a skid or stone boat, or along the ground to its destination. A shovel dozer can get the bucket floor under the block and lift and carry the tree. The trunk usually has to be tied to the top of the bucket, or held so that it will not fall forward. See Figure 7-14 for this procedure.



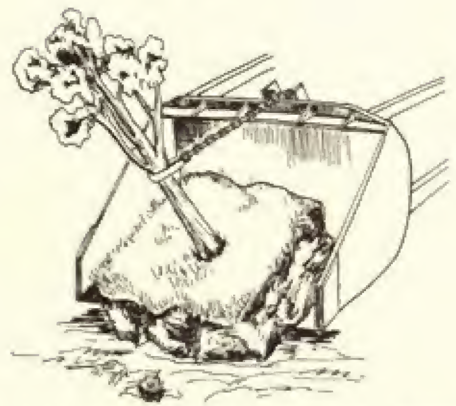


Fig. 7-14. Transplanting tree with shovel dozer

Dipper shovels can often take out good sized trees unharmed by either trenching or direct digging. Draglines and hoes are limited to trees short or flexible enough not to be broken by the overhang of the bucket, and some scarring of the trunk is to be expected.

When conditions are favorable, trees can be machine dug at a fraction of the cost of hand work. Results may or may not be as satisfactory. Risk of damage is greater, except by the trenching method with a shovel dozer.

Planting holes can be dug rapidly by a clamshell or hoe, and less readily by other machines. If the dug soil is poor, it should be removed and replaced with topsoil.

Heeling In. It is often necessary to dig up small trees and shrubs before their new location is ready for them. They should

Fig. 7-15. Heeling in

then be planted temporarily, a process known as heeling in.

A trench is dug large enough to hold the roots and the plants are placed in it side by side or in groups. Enough dirt is shoveled or pushed over them to cover the roots, and the fill and nearby ground are thoroughly soaked. The stems may be upright, or leaned over sharply as in Figure 7-15. If the heeling in is to be for only a few days a shady spot is best. If for much longer, there should be little more shade than the species can tolerate in normal growth. The trench should not hold water for more than a few hours after a rain as the roots may die from lack of air.

Large trees with wrapped balls of dirt can be left standing on the surface of the ground if kept watered and not subjected to much sun and wind.

Delay between digging out and solid replanting always harms a tree. Heeling in and other precautions serve to keep this damage to a minimum, but should never be regarded as good substitutes for prompt and direct installation in a permanent location.

Transplants. A tree which has been transplanted before and has had a chance to recuperate can be moved again with less risk and damage. This is largely because the long roots cut with the first transplanting are replaced by new growth close to the tree, which are included in the ball or root mass that is moved with it the next time.

When small trees are purchased from a nursery for planting in fields where they will have to struggle against the native vegetation, transplants are usually a better investment than seedlings of the same size. Their much higher survival rate more than compensates for their higher cost. On the other hand, if they are to be set in beds where they will receive care, the seedlings may be the better buy.

Another factor is that of height. While a small plant usually sustains less shock and damage from transplanting than a large one, there may be a critical factor of overtopping. If grass and weeds can grow over a little tree so as to cut off its sunlight, in addition to competing with its roots for nourishment, it starts out with two strikes against it. If it is tall enough to overtop its immediate neighbors, its chances are much better, so that the tall seedling may make a better showing than the short transplant at about the same price. However, extra height which is not enough to get it to sunlight will not be of great value.

An exception to the above discussion will be found in trees such as the beech and dogwood which thrive in shade. However, these are not suitable for open field planting.

Pruning. Some roots are always lost in planting from cutting off, scarring, or drying. The remaining roots may not be adequate to supply water to the tree, and their ability to do so is further lessened by the disturbance of capillary water movement by the planting process. Shortage of sap may cause the tree to die, or may weaken it so that growth will be poor and it will be very vulnerable to damage from disease or weather.

If enough branches are cut to restore a

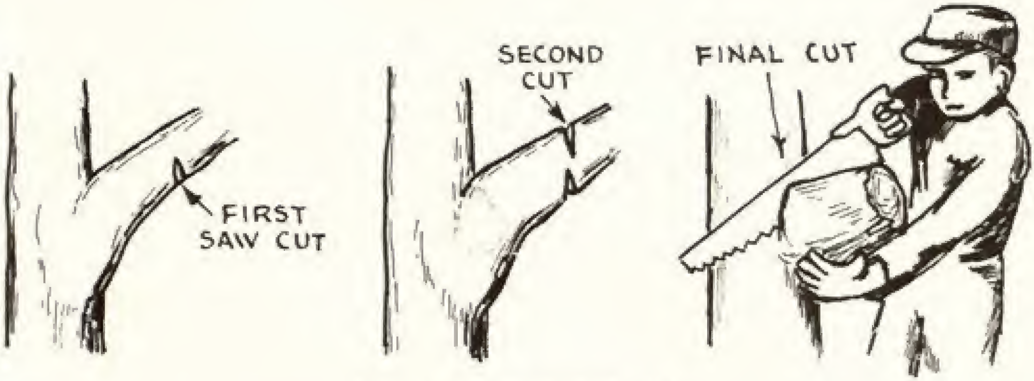


Fig. 7-16. Cutting large limb

balance between the top and the diminished root capacity, damage will be less likely. The type of pruning depends on the variety of plant, and its extent is determined by the amount of root loss, the amount of watering it will receive, and whether it is in shade or sunlight.

Some plants will go into shock if pruned drastically. Others will be unfavorably affected as to ability to produce blossoms or fruit for the next several years, or will lose the pruned branches because of inability to start new buds in the stubs. Because of the great number of plants and regional differences in their behavior, exact information cannot be given here.

A young tree which is meant to grow into a tree shape should almost never have its central or top shoot cut. A new top will grow from one or more side shoots, but the trunk will develop a permanent kink or a weak fork below the cut.

Deciduous (broad leaf) trees and shrubs are usually pruned at least in part by cutting back some or all of the branches. A very drastic pruning that will cause death by shock to some species involves cutting all limbs back to bare stubs. Less severe pruning may consist of trimming the ends which project too far, or removing whole limbs which are crowded or undesirable.

The conifers—pines, spruces, hemlocks, etc.—usually die if they are cut back to bare stubs, and many of them cannot stand any general pruning. Leafage can be reduced by taking out entire branches in places where others will fill in the gaps, or by removing all the lower branches for several feet above the ground.

Care must be taken in removing heavy limbs not to allow them to tear the bark below the cut. The three steps shown in Figure 7-16 should be followed. The final cut should be as near to flush with the trunk as possible, and the wound should be covered promptly with tree paint.

Watering. Watering a freshly transplanted tree or shrub serves not only to supply it in such quantity that even injured roots can take up enough, but also settles the ground so that it will be better able to supply them with natural soil moisture afterward.

In dry seasons watering should be continued for days or weeks, depending on soil character and moisture, and the degree of adaption the tree makes to its new environment. Watering may have to be resumed if extreme dry spells occur within a year or two of the planting.

The tree should be set in a slight hollow, or a dike should be built around it to retain water. The hollow is preferable as it will catch rain also.

Subdivision Planting. In real estate developments, street grading often precedes the selling of the lots by some years. The appearance and value of the development can usually be enhanced by planting of shade trees immediately after road work is

completed, so that they can have maximum time to grow.

Unfortunately, trees planted in fields or freshly graded land usually do not prosper unless cared for, and neglect may cause the loss of most or all of them. However, there are planting procedures which will enable them to fend for themselves quite well.

The trees should not be taken from dense woods or heavy shade, as sudden exposure to full sunlight is likely to cause burning and cracking of the bark. They should have adequate roots with wrapped balls of dirt. If they are not wrapped, they must be moved promptly from their original location to the new one, with roots protected from sun and wind.

The tree locations are indicated by stakes or other markers, set by instrument, measurement, or eye.

A clamshell is used to dig the holes. Unless the dirt is very hard, a small size will be adequate. The hole is dug oversize in both depth and area for the tree to be planted, to allow for errors in calculation and for placing topsoil. The dirt is loaded into a truck and hauled away.

If the trees to be planted do not have balls of dirt, the holes are refilled with good topsoil. This can most conveniently be brought by truck, picked out by the clamshell, and placed directly in the holes. The soil in the truck bottom which cannot be scraped up may be dumped at a hole, and hand shoveled in or left in the truck when it goes for another load.

If the trees are balled, sufficient topsoil should be placed in or beside the hole to set the tree properly.

Dirt is tamped around the tree and water supplied in the conventional manner. If there is any question about the quality of the topsoil, a moderate amount of manure or general fertilizer should be mixed in the surface before watering.

The ground for several feet around the tree should then be covered with material

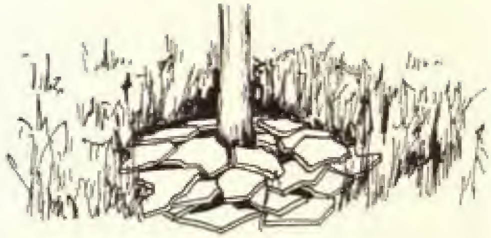


Fig. 7-17. Tree protection against sod

that will prevent grass and weeds from competing with the tree for nourishment. When available, flat stones laid so as to overlap each other as in Figure 7-17 are the most effective cover. Scrap shingles or other flat pieces of wood are a good second choice. If neither are available any mulch or ground cover such as wood chips, hay, or leaves may be used. These last materials need to be placed in a layer four to six inches thick, and may require renewal after a few months or a year.

It is a good precaution to guy trees against blowing over, but it may not be necessary if they are small or have heavy roots.

Trees planted in this manner are supplied with adequate nourishment, and are protected against the competition of vigorous sod.

DRIVEWAYS

Most home landscaping involves planning of a driveway. It may be a straight connection to a street a few feet away, or a long roadway involving considerable problems.

Short straight drives can be as narrow as seven feet for use by passenger cars only, but eight feet is more comfortable. A long drive, one which is in a slot between vertical walls, or any drive which is to accommodate trucks, should be at least ten feet in width. Curves should be one to three feet wider than straightaways, the sharper turns requiring the greater width.

Where possible, the entrance from the street should be flared wide enough to

permit turning into it from the near side of the street. An effort should be made to avoid entering the road through a deep cut, between large trees, or in or very near a curve, as any of these features add to the danger of accident.

Sidehills. A long driveway of the farm or estate type may have to cross a hill slope. It is notched into it in the same way as a pioneer road. However, since it is a permanent improvement which should have a pleasant appearance, special procedures are followed.

Such a drive serves not only as an automobile route but also as a drainageway. Unless diversion ditches are made above it, whatever water flows down the slope will land in the driveway cut, and flow down it or across it. Unless an ample channel is provided, the drive may often resemble a stream bed.

A driveway crossing the bottom of a long hillside should be fourteen feet wide, including the drive, shoulder, and gutter, but not the slopes. The gutter should be at least three feet wide and deep enough to carry all the water. It can be relieved at frequent intervals by diagonal cross drains to the lower slope. The drive cross-section may be crowned or sloped oppositely to the hill, but should never slope with it. See Figures 7-18 and 8-1.

The cheapest gutter is sod and it may hold on quite steep slopes if well established. Temporary diversion ditches can be made with a plow to keep much of the water off until it is well established. Stone, concrete, and blacktop are water resistant, but are subject to frost heaving unless on a stone or gravel base.

The slopes of the cut and fill should be topsoiled and seeded. They are often too steep for mowing.

Garage Level. Driveways offer minimum trouble in use and maintenance if they are nearly level. Unnecessary expense and inconvenience may be caused by placing the garage so that grades are created or exaggerated.

If the driveway is long, the garage should be at about the grade of the ground around its entrance after landscaping. If the drive is short, the garage should be at about street level.

It is unusual for a garage to be higher than the grade around it, but it is very common practice to place it under the house at cellar level. In this case the driveway often must enter it through a deep cut bordered by steep slopes or retaining walls, and usually descends more or less steeply as well.

A descending drive must level off several feet outside of the doors, and must not do it so abruptly as to cause a car's bumpers to scrape when entering or leaving. Extra width is needed between walls. One or more grating drains should be provided outside the doors, with plenty of capacity. Drainage from a long drive or from the lawn should be diverted to other drains or

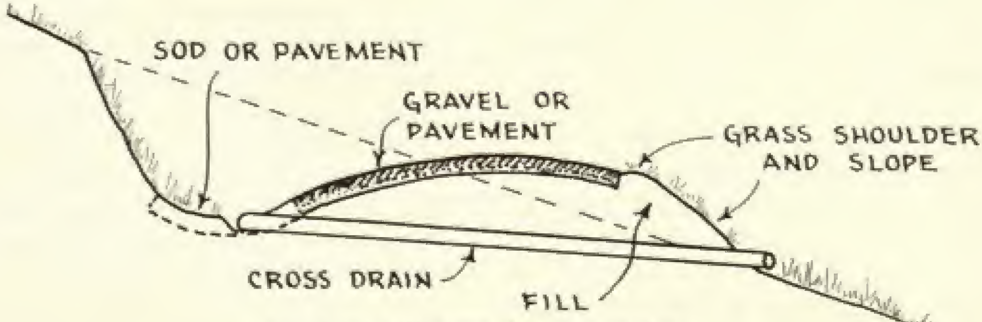


Fig. 7-18. Hill slope driveway section

channels. Failure to observe both of these precautions may result in a flooded garage or cellar. It is also necessary to keep the area clear of leaves and trash that might block the drain.

If the drive is short, its slope will be determined by the difference in level between the garage and the street. Driveways as steep as 30 percent grade are in use, but they are both difficult and dangerous.

Any steep drive requires care in designing the vertical curves at each end so that the center of the car will not scrape on a convex curve, nor its bumpers hit on a concave one. There should be a parking place which is moderately level if possible.

In climates where freezing weather occurs, steep grades may become dangerous or impassable. If there should be a choice, a grade up to the garage is to be preferred to one leading down to it. In the former case, it is usually possible to reach the street, and the importance of getting somewhere is usually greater than that of putting the car in the garage rather than leaving it at the curb. Also, drifting snow may entirely fill a cut to a low garage, from which it will probably have to be dug rather than plowed.

Snow Melting. Heating pipes can be installed under driveways, walks, and outside stairways to prevent snow and ice from resting on them. Cost of such an installation is now between one dollar and three dollars a square foot of surface, and under many circumstances it is a worthwhile investment. Operating expense is said to be only a fraction of the cost of shoveling or plowing.

The preferred method is to lay wrought iron pipe or copper tubing in the pavement slab or immediately below it, and circulate an antifreeze solution heated by a heat exchanger in the house steam or hot water boiler. It can be turned on and off by hand, or by automatic controls operated by the weight of the snow, or by its interference with a light beam reflected off a polished surface to an electric eye.

The system must have ample capacity, or will occasionally do more harm than good. If it does not quite keep up with the snowfall, at the end of the storm it may leave the area covered by a layer of slush, which might then be frozen by an extreme drop in temperature and kept frozen until the weather warmed slightly.

Anyone considering installation of this protection should consult some authority such as "Snow Melting" by T. Napier Adlam (The Industrial Press, 1950).

Turnarounds. A driveway which does not include a turning place requires that a car be backed out of it or into it. This is entirely impractical on long or curving drives, and is a nuisance and a danger in any case. Wherever lot size permits, a turnaround should be provided.

The best way to lay one out is to have the people who are to use it make some trial turns, add a few feet to the space they require to allow for carelessness or a bigger car, and build the drive accordingly. If there is no opportunity to practice, any of the layouts shown in Figure 7-19 should prove satisfactory.

Allowance should always be made for car overhang. This may be two feet front, up to four feet rear, and eight inches at the sides. It is desirable to have a curbing that will keep the wheels about a foot away from vertical walls to protect the car from scraping at the side.

Extra space may be provided in a turnaround for parking, or to supply peace of mind to uncertain drivers.

Surfacing. Four inches of good bank gravel, crushed rock, shell, or similar materials should be stable enough for a house drive on well drained soil. Under average conditions six inches is safer, and when the ground is soft and wet, eight inches to a foot or more may be required.

A stone fill underneath can be used to

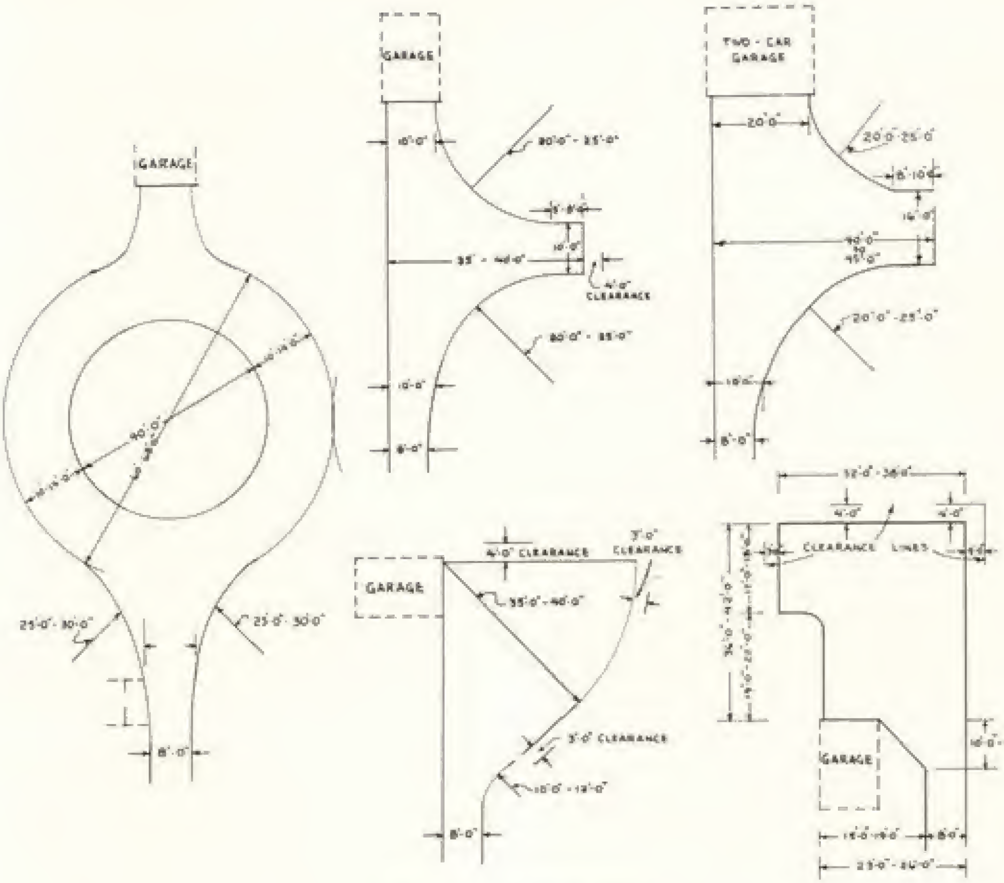


Fig. 7-19. Turnarounds

reduce gravel requirement. Any flat stones near the surface should be set on edge so that they will not rock and disturb the top dressing.

If the driveway is long, it may pay to try to get by with a minimum depth and add more material to any soft spots as they develop. However, it is often necessary to dig away the softened gravel, as it mixes with mud underneath. If the driveway is short or the budget liberal it is good practice to put down a safe depth in the first place.

Cinders should be used only for temporary drives or as a base, as they break down under traffic and become muddy.

These materials may be used for both the bulk and the surface of the drive, may be given a surface treatment, or serve only as a base course.

If used alone, varying amounts of difficulty may be found with loose stones, gullies, dust, tracking small particles into houses and cars, muddy surfaces, ruts or mudholes, or scattering on the grass, depending on the kind and quality of material used and the circumstances.

Calcium chloride, either scattered on the surface or mixed in, will prevent the drive from becoming dusty, and will help to hold it against washing and scattering. It should not be used in the immediate vicinity of the house where it might do damage if tracked in.

A thin layer of loose pebbles or fine crushed rock makes an attractive surface for light and slow-moving traffic, but scatters under fast traffic. Snowplows are likely to move a large part of it to the lawn.

A thin oil may be applied to soak into the surface and bind it. This eliminates

dust and reduces erosion but might be too "dirty" for use on foot for some time.

Tar and asphalt preparations are available which are spread on the surface and covered with sand or chips. They provide a surface which is hard and clean except under a very hot sun, are attractive in appearance, and are dust-proof and erosion-resistant. The first application is usually short-lived unless the base is exceptionally rigid, as the thin layer tends to break up over any soft spots. Resulting holes can be filled with a prepared mixture or the whole surface can be scarified and retreated. Sometimes the holes are patched and a new surface application made. In either case each treatment produces a stronger surface than the previous one.

In many localities either cold or hot mixes of asphalt, sand, and crushed stone may be obtained. These are spread by hand shovels, rakes, and light machinery, and rolled with two to five ton rollers. Compacted thickness may be as little as one inch on a good base, or two and a half inches or more on a poor one. It is usually poor economy to place this expensive material on a soft or wet subgrade. When in doubt about the thickness required, the heavier layer is advisable. This surface is clean, hard, and long lived.

Regular penetration macadam roads may be built of rolled crushed rock soaked after placement with hot tar or asphalt. A seal coat is placed over this, and sand or chips scattered to prevent sticking. This construction is chiefly used in areas where ready-mix is not available, or where the job is a large one.

Bituminous pavement takes several months to reach full hardness. If laid in late autumn it may be severely damaged by careless snowplowing, and will be especially vulnerable to breakage over soft spots in the base course.

Curbing of masonry or steel strips protects driveway edges.

Reinforced concrete slabs should be about five inches thick for cars only, and about seven if heavy trucks must be carried occasionally. The surface layer can be tinted.

Some economy can be found in building short straight drives of two parallel ribbons of pavement instead of a full width slab. The saving is not proportionate to the reduced area because of the extra expense of forms or edging.

AGRICULTURAL GRADING

Need for Grading. It is often necessary or desirable to regrade land in order to use it for farming. In arid regions, land is leveled to permit even distribution of irrigation water. In semi-arid climates, sloping land may be terraced to hold rainfall behind dikes so that it will soak into the ground instead of flowing off.

Where the rainfall is adequate or excessive, terracing may be necessary to reduce washing of soil from cultivated slopes. Under any conditions of climate or soil, leveling may be desirable to allow use of large or high speed machinery. Alone or in conjunction with underdrainage it may increase yields by eliminating burning out of crops on ridges and drowning in hollows.

Agricultural grading differs from other types of earth moving in the large areas to be treated in proportion to the money available, the flexibility in engineering requirements to suit conditions and cost factors, and in problems relating to the handling of topsoil.

Cuts and fills are typically shallow, vertical movement of soil is slight, and horizontal movement is relatively great.

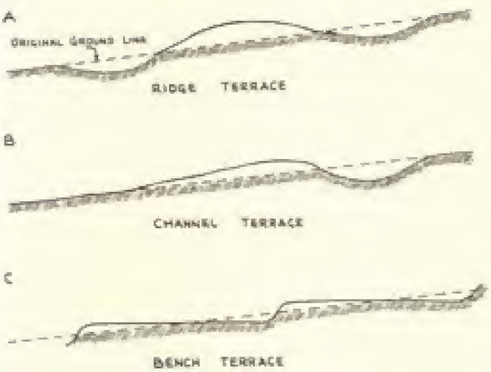


Fig. 7-20. Terrace types

TERRACING

Terracing land is the grading process of interrupting slopes with ridges, channels, or benches, or combinations of them, in order to slow or stop the flow of rainwater, and to prevent harmful soil erosion.

Terracing may serve to hold water on the slope so that it will soak into the ground; allow water to flow off it while keeping the loss of soil to a minimum, or to reduce slopes so as to make them more readily workable or irrigable.

Terrace Types. Three principal types of terrace are used. Each is constructed along level or contour lines. The ridge terrace, Figure 7-20 (A), is a ridge built of soil obtained from both sides. The channel terrace, (B), is a ridge constructed of dirt from the upper side only, and the channel formed by this excavation is an essential part of the structure. The bench terrace, (D), has a stair structure with steep risers separating relatively flat cultivated areas.

Ridge and channel terraces are usually built with sufficiently gentle slopes to allow farm machinery to work along or across them. Best results are obtained if farming operations are done parallel with their center lines.

Ridge Terraces. The ridge or absorptive-type terrace is used primarily to conserve water in regions of deficient rainfall. Each ridge serves as a dam for a pond, which is deepest in the excavated area immediately above it. Water may also be impounded in the trough formed below this ridge by borrow of material. See Figure 7-21.

A larger area and quantity of water can be held on slight gradients than on steep ones, by any one size of ridge. Not only is more water retained per yard of dirt used in the ridge, but its distribution over the land is more uniform.

Too great a depth of water may drown out crops immediately above the ridge.

It is ordinarily not economical to construct terraces for water conservation alone on slopes over 3 percent, and structures for reducing soil erosion are more often of the channel or intermediate types.

Overflow channels may be provided to carry off rain in excess of that for which the system was designed. These should be protected like channel terrace spillways.

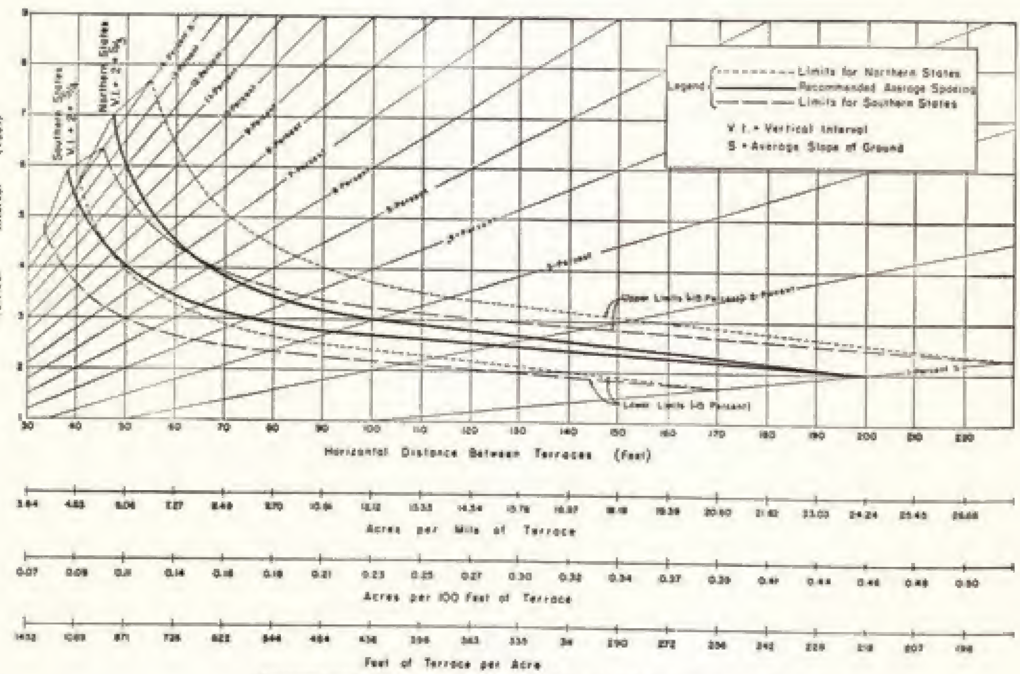
Channel Terraces. Channel or drainage-type terraces are essentially shallow diversion ditches which catch water flowing down a hill and lead it off to drainageways that have been protected against erosion.

The channel depends on the ridge of excavated material for much of its capacity. Its grade is flat, or nearly so, so that only extremely fine soil particles can be carried by the water it discharges.

Bench Terraces. The principal application of bench terraces in the United States is in connection with irrigation. If the original slope of the land is greater than that of the graded fields, each field will consti-

Courtesy U. S. Department of Agriculture

Fig. 7-21. Ridge terraces after rain



Recommended terrace spacings and related data for channel terraces.

Courtesy U. S. Department of Agriculture

Fig. 7-22. Channel terrace data

tute a terrace, separated from fields above and below by comparatively steep slopes.

Benches may also be made in steep cultivated land by leaving narrow contour strips in grass or other permanent vegetation. Soil washing from the wider strips between will be caught by the grass and will tend to build up the low side of the cultivated piece, while its top is lowered by erosion. This process, often accelerated by plowing so as to throw dirt downhill, will ultimately result in gentle slopes separated by steep banks.

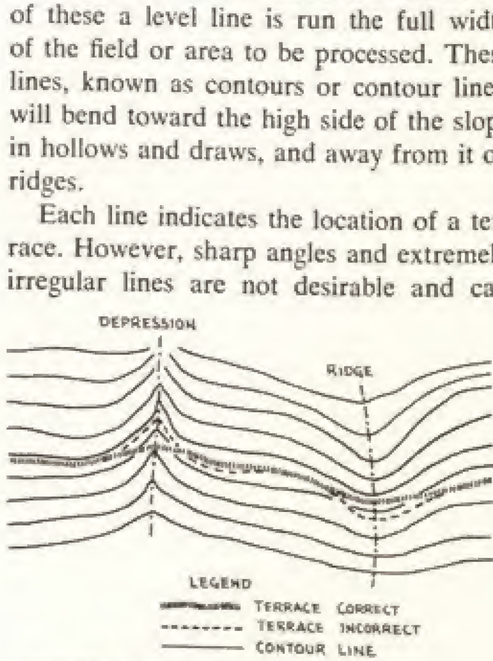
This work is ordinarily done by farmers without assistance from contractors.

Surveying. A terrace system must be carefully surveyed and planned before construction starts.

The interval between terraces may be taken from the chart in Figure 7-22, or better, determined after conference with soil conservation specialists.

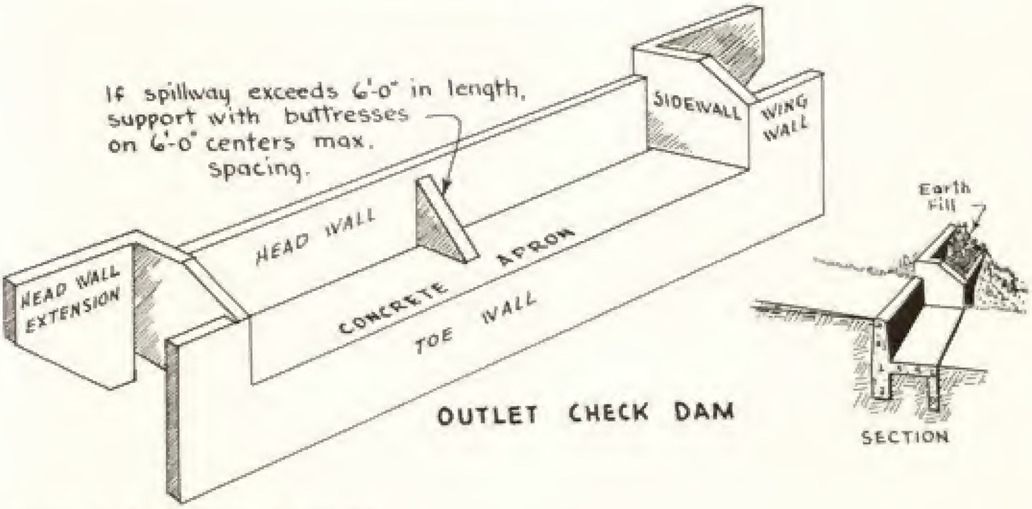
Stakes are placed from top to bottom of the field at the selected intervals. From each of these a level line is run the full width of the field or area to be processed. These lines, known as contours or contour lines, will bend toward the high side of the slope in hollows and draws, and away from it on ridges.

Each line indicates the location of a terrace. However, sharp angles and extremely irregular lines are not desirable and can



Courtesy U. S. Department of Agriculture

Fig. 7-23. Terrace line correction



Courtesy U. S. Department of Agriculture

Fig. 7-24. Check dam

often be reduced or eliminated by minor adjustments, as in Figure 7-23. Farming is simplified when adjoining terraces can be made parallel.

If an angle in a gully is eliminated by moving the line downhill, the terrace ridge will have to be built higher above ground level to preserve its grade, and water will be ponded behind it.

If the line is moved uphill to cut off a bend on a ridge, the channel will have to be dug deeper to allow flow of water through it. However, such a ridge may be used as a divide or drainage head, in which case little water will be present.

Stakes are ordinarily used only for location guides, but may be marked with grades where the terrace is to be higher or the channel deeper than standard.

It is desirable that the top of the terrace system be also the top of the drainage area. The top terrace should serve the same width of ground as those below it. If a larger area must be served because of flow from higher fields, the channel capacity must be increased proportionately, or some other type of intercepting drain used.

Grades. Ridge terraces usually have a level grade.

Channel terraces may be level for the section most distant from the outlet, and slope increasingly to about a ½ percent grade at the outlet.

Drainage is normally from ridges toward hollows.

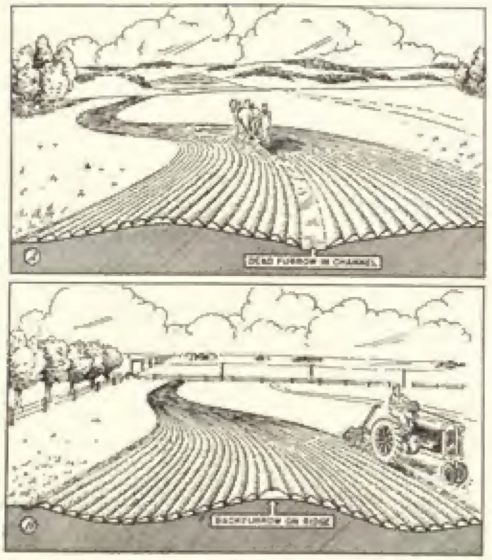
Short terraces require less maintenance than long ones.

Outlets. The discharge from a terrace should be into a waterway that is capable of carrying the water directly down the slope, without eroding. Shallow depressions carrying a permanent sod are often satisfactory. These should have enough drop from side to center to insure gathering of all water discharged from the channels, but should not concentrate enough flow at the center to cause erosive velocities.

The strength of the sod, as affected by fertilizing and grazing, and the condition of the soil will determine the maximum safe gradient for a meadow outlet. This is ordinarily six percent or less.

Sod should extend several feet above flow lines on the sides of the waterway. Steeper or narrower channels may be protected by ungrazed and uncut growth of grass, weeds, bushes, or trees.

For extreme conditions, a channel pro-



Courtesy U. S. Department of Agriculture

Fig. 7-25. Plowing to preserve terrace

tected with check dams (Figure 7-24), pavement, or other artificial structures may be required. Steep banks require sod or artificial flumes for the terrace discharges.

Permission of owners of land below the farm must be obtained if the terrace system alters the path or concentration of water on their properties.

Outlets MUST be completed and protected before terraces are built.

Construction. Terrace construction is primarily a matter of sidecasting. The work is commonly done with graders of either the powered or towed types. Bulldozers working at right angles to the terrace are also effective, particularly in the channel type.

Belt loaders, of both standard and special terracing models, give excellent results.

If the channel or cut depth is greater than that of the topsoil, a barren strip will be left which will yield poor crops. This damage may be reduced by overcutting the channel so as to leave it below grade, and blading some topsoil from above to cover it.

Maintenance. Terraces will serve their purpose best if plowing and cultivating is done along contour lines—that is, parallel with the terrace lines.

A terrace can be enlarged by plowing so that dead furrows are in the channels and lands on the ridges, as in Figure 7-25.

Any accidental blocking of a channel or damage to a ridge should be repaired immediately, as it might cause the terrace to fail in a heavy rain, with possible destruction of the terraces below it.

GULLIES

Characteristics. So far as this discussion is concerned, a gully is a drainage channel that has become so deepened or enlarged that its banks are unstable, and tend to extend destructively into surrounding land.

Control of gullies is largely an agricultural problem, but may also be required to protect highways or structures.

Gullies are a sign of the beginning of a new cycle of erosion which tends to dissect smooth slopes or high levels of ground into table-lands separated by steep walled channels or canyons. Unless controlled, it will eventually narrow such tables into peaks. Geologically, they are small examples of the type of stream erosion which carves rising land into mountains.

The new erosion cycle may be started by land rising so that steepening channels add to the velocity of flowing water; by lowering the outlet of a stream with the same result, or by reducing the resistance to erosion of the land.

Gullies are caused most frequently by the destruction of the vegetation which protects the land surface, although they may also be started by lowering of outlets, due to highway or stream channel work, or land slips.

The majority of gullies contain intermittent streams which flow only during or immediately after rains, or in wet seasons. Permanent streams are less often affected as their beds are unsuitable for agriculture. These are most apt to be raised and choked

Courtesy U. S. Department of Agriculture

Fig. 7-26. Active gully

by silt deposits resulting from bad farming.

Growth. When a slope is covered with vegetation, whether sod, bushes, or forest, rain water tends to move downward as a flowing sheet, and is only gradually gathered in definite drainageways. Its eroding action on the ground is slight as it is held from contact with the dirt and its velocity is lowered by stems and roots that form a protective mat.

If the vegetation is removed by plowing, disking, close grazing, or fire, the water comes in direct contact with the soil and tends to remove the surface particles. This effect is usually rather uniformly distributed at first, and is called sheet erosion. It can be reduced to slight proportions by proper farming, including contour plowing and cultivating, and terracing or return to sod when necessary.

Erosion is most active where the amount or velocity of water is greatest, or the soil is least resistant. Such places tend to wash out more than the surrounding area, and then, being lower as a result, will catch the runoff from a larger area, increasing the quantity and velocity of water, and its eroding effect. The deepening of the channel therefore tends to build up forces which will make it deepen more rapidly.

In its early stages such a gully may be destroyed by plowing or harrowing, so that it is choked by clods and some of its water is diverted elsewhere. However, unless close growing vegetation is planted, or weeds allowed to grow, new storms will re-form the channel or create new ones nearby, and they may eventually become too deep to be choked by plowing or even to be crossed by a plow.

Once a gully is formed it enlarges by three separate processes. One of these is channel erosion—the scouring action of the water deepening the bottom. This is accompanied by the falling in of the sides as they are undermined.

The upper ends (heads) of gullies advance into the land by waterfall erosion, both along the main drainage line and branches which are acquired. Subsoil is often less resistant to erosion than topsoil. Water pouring into the gully will cut it into steep banks, undermining the topsoil and causing it to fall. The impact of the

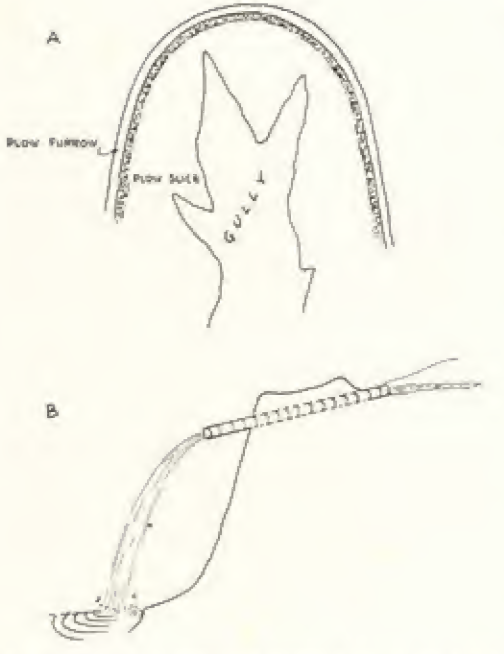


Fig. 7-27. Diversion of water from gully head

waterfall on the bottom gouges holes which accelerate channel erosion.

Waterfall erosion usually produces a gully with a U cross-section. It becomes less active as it approaches the head of drainage and the quantity of water is reduced.

If the subsoil is equal or superior to the topsoil in resistance, waterfalls will not develop, but the gully can progress by extensions of channel erosion.

The third major factor in extending gullies is sloughing off of soil due to alternate freezing and thawing, or following saturation by heavy rains. This process is most active on southern and eastern slopes, and will eat through a field with little regard to slopes or drainage lines.

Continued progress of either waterfall or sloughing erosion depends on sufficiently active channel erosion to remove the loosened dirt.

Once well established, a gully will continue to enlarge even if the surrounding land is planted in erosion resistant vegetation, as the head and side slopes will undermine the surface.

A gully may advance downstream by channel erosion. More often, it deposits debris in a delta fan at or near in its mouth, so that the land is built up. This process is destructive also as it buries topsoil under subsoil.

Damage. The damage from gullies includes actual destruction of farm land, cutting up fields so that they cannot be worked economically, lowering the water table so that crops dry up, undermining buildings, roads, and bridges, burial of lower lands under barren subsoil, and choking of streams with silt.

An individual gully can do damage amounting to many thousands of dollars, and the national loss from them is in the hundreds of millions. Their control is therefore of great importance.

CONTROL

Control measures after gullying has started may include diverting water to other drainageways, planting, breaking down walls, building check dams, and proper use of the affected land.

Diversion. Water entering the gully can sometimes be diverted by plowing an arc around its head, as in Figure 7-27 (A). The slice should be turned toward the gully to make a dam to back up the furrow.

More often it is necessary to build dams or to dig ditches. Dams are safer, as a new ditch or even a plow furrow may start a new gully, unless watched and controlled.

Where diversion is not practical, waterfall erosion may be checked by conducting the water into an overhanging pipe or flume, as in (B).

If water can be permanently diverted from a gully, the walls will eventually break down into stable slopes, which will be covered and held by volunteer vegetation.

Planting. A gully may be checked by planting. Small ones are best broken down

and planting with pasture grass; larger ones are better handled with shrubs and trees.

The plants should be of types that can grow well in poor soil, have extensive root systems, and will not be injured by partial burial. If the ground is damp most of the year, willows are probably the most efficient, particularly as they will grow from poles or logs secured horizontally in the floor across the direction of flow, thus providing mechanical control while roots and stems are sprouting.

Black locust grows vigorously in poor soil, has a widespread root system, and yields a crop of fence post material. Many of the pines do well in barren soil but their roots are not as strong.

Vines such as kudzu and honeysuckle are used successfully.

Whatever plants are chosen, enough soil should be loosened to give them a good grip. Whenever possible, fertilizer, manure, or topsoil pockets should be provided to give them a good start. Animals should be fenced out of the area.

It is usually not practical to plant very steep walls. When vegetation is growing well on the bottom, soil caving from the walls will be held so that the slopes will gradually become less abrupt, and will allow growth of self-seeded plants.

It is often necessary to divert water or to reduce its velocity in the channel before planting can be successful.

Breaking Down Walls. The healing of a gully scar can be greatly accelerated by breaking down the walls into slopes gentle enough to support vegetation. When practical, it is desirable to have the slopes such that farm machinery can cross them in any direction.

Very small gullies can be broken down with plows and other farm implements. Somewhat larger ones can be reduced by graders or angle dozers working parallel with the edge. Big ones require dozers pushing the bank more or less straight into the gully, or a dragline pulling it from below.

Gullies may be of such large size—depths of fifty feet or more—that it is not economically practical to grade them in even with the largest machinery.

The new slopes produced are planted in somewhat the same manner as road banks.

Check Dams. In order to obtain permanent control, it is usually necessary to slow, stop, or reverse the process of channel erosion. An actively cutting channel will steepen and undermine its banks and the new grading or planting they support.

A channel interrupted by dams or other obstacles will tend to silt up to a higher gradient, reducing the height of its walls and encouraging plant growth.

If flow is only occasional, close plantings of bushes in the channel and on its banks may be sufficient. These are often planted in lines across the gully, and protected against washing out by wire stretched across deeply driven posts.

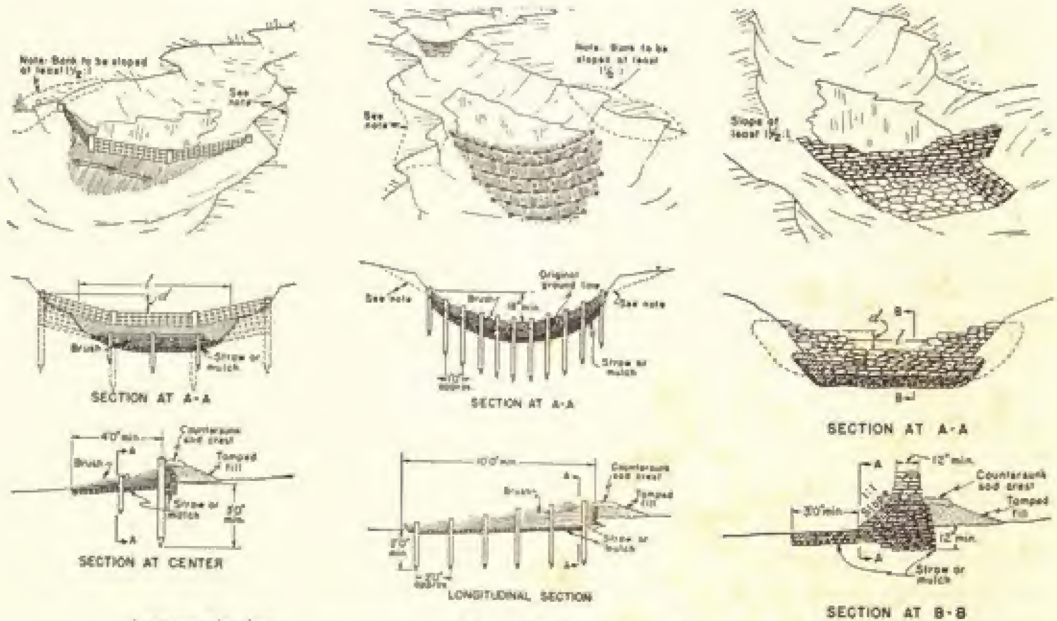
Sod, combinations of cut brush and wire, or stone or logs, can be used in building check dams. Some constructions are shown in Figure 7-28.

In general, any structure which water cannot get under or around, which is tight enough to prevent dirt from going through it, and is strong enough not to be washed out, will serve as a check dam.

IRRIGATION SYSTEMS

The design of an irrigation system is an engineering problem out of the field of this book. It is in order, however, to mention briefly some of the factors.

Wells. Water may be obtained from wells, occasionally by natural flow but more often by pumping. Such water, if used in the immediate vicinity, involves minimum piping and distribution difficulties. The most serious problem is the likelihood of using too much water, so that wells must be deepened or new ones drilled to keep in touch with the falling water table. In many



A woven-wire dam.

A brush dam in common use.

A loose-rock dam.

Courtesy U. S. Department of Agriculture

Fig. 7-28. Gully check dams

localities such over-pumping will eventually reach salty or alkaline water unfit for agriculture.

River water may be pumped up to the land to be benefited, but more often flows onto the land from a higher point in the river. A ditch or canal is cut from the stream, and run horizontally or with a very slight gradient along the side of the valley. The land between the canal and the river is irrigated by gravity flow from the canal into ditches, and from them onto the fields.

Most rivers have a wide variation in level so that such a canal might be subject to being left dry at times and flooded out at others. A more constant level can be obtained by damming the stream below the canal entrance to keep the water high enough to enter it, and by providing gates and a protective dike to prevent flooding. A dam and control gates above the inlet will permit regulation of the river level and inflow.

In dry climates streams may flow only during the winter and spring or in occasional floods. Water from such a source may be useful for crops which will mature in the wet season or as a supplement to water obtained from wells, but the cost of handling it may not be justified.

Reservoirs. Such streams may be utilized by building one or more impounding reservoirs upstream. These will permit storing the heavy flow of some months to be released in drier periods. Large reservoirs of this type may be ideal sites for hydroelectric plants, as the irrigation water can be used to turn turbines on its way through the dam.

Most of the large irrigation systems of the United States depend on storage reservoirs.

Lakes may be used as sources of water. It may be pumped up onto adjoining land or conducted through siphons or canals to lower land. Occasionally, a lake may be tapped by means of a tunnel and used for stream regulation in the same way as an artificial reservoir.

Sediment. Direct river flow into an irrigation canal carries varying quantities of sediment with the water. The flat gradients and slow motion of the water in the system will cause extensive silting, which will ultimately reduce water capacity, may cause continuous trouble in operation of gates and other devices, and will clog pipes. The design should take this quality of the water into account. Very dirty water requires oversize waterways, steepened gradients, particularly in pipes; cleanout traps or flushing devices for pipes, and access to all ditches for cleaning by machinery or by hand.

Upstream reservoirs catch most, or sometimes all, of the nonsoluble sediment. Any residue may be still further reduced by settling basins.

Dirty water has certain advantages. In most localities it is good for the land, carrying topsoil and minerals which help to replace natural losses. It also tends to seal leaks in canals and ditches so that wastage by seepage is reduced.

Its disadvantage is the greatly increased cleaning and maintenance work required, which is so important a problem that most irrigation engineers will secure clean water whenever possible.

Canals. The main canal may be an unlined ditch or a ditch lined with special impervious soils or a concrete or other artificial lining. If it is carried well below natural grade at any point, it is customary to use a lined tunnel or concrete pipe at such a section.

The unlined ditch is the most economical to construct, and may be used where soils are impervious, where the water carries enough sediment to seal leaks, or where the supply of water is so large that seepage losses are less important than the expense of preventing them.

A ditch may be lined, either in sections or as a whole, by placing a layer of clay or impervious silt on the bottom and sides.

Courtesy U. S. Department of Agriculture

Fig. 7-29. Concrete lining in irrigation canal

This may be placed in a dry ditch, or fine clay may be added to the irrigation water until it has coated the canal.

A ditch must have bank slopes which will not cave or slump into the water. Vegetation may be used to hold dirt banks and will permit steeper slopes, but its consumption of water is often excessive. Banks should be protected from erosion by surface water.

Concrete lining is expensive construction, and if properly done is most satisfactory. Such leaks as occur will generally be localized and comparatively easy to find and repair.

Damage from leaking canals is not confined to the water loss and the breaking down of the canal structure. Farm land near the leaks may be rendered unusable by excessive water and resulting alkali deposits, unless subdrainage is provided.

Pipes. Either ditches or pipes may be used to distribute the water from the canal. Ditches are more economical to construct, but cut up the land, are expensive to main-

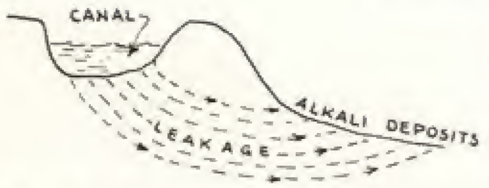


Fig. 7-30. Damage to land from canal seepage

tain, form breeding spots for insect pests, are a hazard for children, and may allow substantial water losses by seepage and evaporation.

Pipes may be concrete, glazed tile, iron or steel, or composition. The first two sometimes separate at the joints when filled with cold water, either after lying empty or being used to carry warm water. Iron pipes may corrode rapidly due to alkalies in either the soil or the water.

Various methods have been developed of joining concrete and of treating iron pipes, which reduce the difficulties mentioned. On the whole, pipes require less maintenance and waste much less water than ditches. However, they must be laid on steeper grades to prevent silting. If they become blocked, they are very expensive to clean.

Large farms or ranches may control an entire irrigation system, but water is usually distributed to a number of users by a water

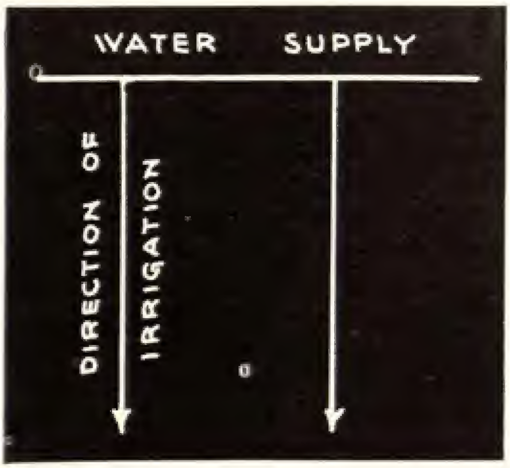


Fig. 7-31. Direction of irrigation

district or other government agency, or by a water company. One water gate or weir is usually provided for each land unit, and distribution within that unit is cared for by the farmer himself.

This may be handied by running a pipe line along one edge of the field, with standpipes and valves at ten to twenty foot intervals. If the field is long several distribution lines may be used, connected by a main.

Ditches may be used instead of pipes but they require more maintenance and may interfere with tillage.

The "direction of irrigation" is the direction the water flows on the surface of the field from the distribution pipe or ditch. It is generally at right angles to the pipe.

LAND LEVELING

Slope Patterns. Land leveling may be divided into six classes, according to the result obtained. These are:

1. Spot grading.
2. General downward slope away from water supply—for sprinklers.
3. Uniform grade in direction of irrigation.
4. Uniform grade in direction of irrigation and at right angles to it.
5. Uniform grade in direction of irrigation and exact level at right angles to it.
6. Exact level.

Spot grading consists in removing humps or filling hollows, without establishing a uniform grade in any direction. It is sometimes done in advance of better leveling for irrigation, and is of general use to make possible faster tillage and more even production.

If water distribution is to be by means of sprinklers, perfectly uniform slopes are not required. For water distribution, it is only necessary that the land have a general slope down from the source of water. In climates where deep freezing of soil occurs,

the slope should be uniform enough to make possible drainage of sprinkler pipe laid at a fairly regular depth.

When the water reaches the individual plants by flowing on the surface of the ground, it is necessary to have an almost uniform slope in the direction of irrigation. The steepness of slope may be determined by the character of the soil, the crop to be planted, the original grade, and the rate of water use.

Economies may be affected on many plots by leveling only in the direction of irrigation, and following the original profile at right angles to it. This type of job is used chiefly in orchards which can readily be cultivated into ridges that will regulate water drifting across the field.

Choice between the fourth and fifth method will depend largely upon economies in working over the natural grade. In very large fields, the two-way slope will facilitate movement of water through the cross distribution pipes. The cross grade should be so slight that even light ridging will prevent sideward drift of the water.

Entirely level plots are usually limited to rice fields, and alfalfa and other crops which can tolerate flooding.

Flow and Absorption. The rate of water flow and absorption should balance so that water will reach the lower end of the slope in sufficient quantity for the crop, without flooding or running off. In practice, this balance may be difficult to achieve, and provision is made for draining off excess water when necessary.

Increase of gradient will accelerate the flow and decrease the rate of penetration. Light sand or gravel soils absorb water rapidly and require steeper grades than clay, which may be almost waterproof unless freshly loosened.

The maximum gradient would be below that which will cause the soil to wash and gully during irrigation or heavy rains. The minimum is flat.

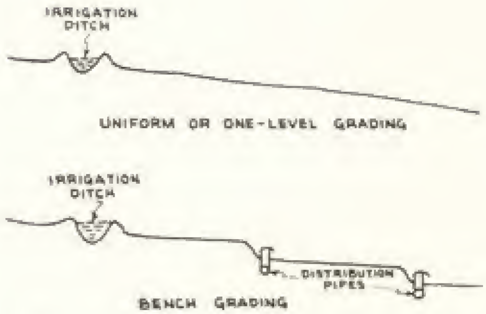


Fig. 7-32. One-level and bench grading

If the maximum practical gradient is not sufficient to move the water the length of the field, additional distribution lines can be installed. Very porous soils require pipes and sprinklers.

Figuring Gradients. Earth moving should be kept to a minimum to save money and to conserve topsoil. If conditions justify the use of any one of several slopes, the one will be chosen which conforms most closely to the natural topography.

If the steepest possible gradient is so much flatter than the original grade that excessive earth moving will be required, because of deep cuts at the top and high fills at the bottom, the field may be divided into two or more levels or benches. These will have the desired slope and will be separated by steep banks. A separate water line is required for each bench.

The high corner or end of the field must be below the level of water in the ditch or its head in the standpipe.

The new gradient must usually be placed at a level, or levels, where cut and fill will balance, as cost may be greatly increased by bringing in borrow or dumping surplus soil. After the surrounding areas are largely under cultivation, borrow or disposal might not be possible. Occasionally, special circumstances, such as nearby channel or road construction, might make transfer of material profitable.

Topsoil is not a problem in many arid valleys where soil is fertile to a considerable

depth. However, when topsoil is thin and rests on layers of soil which are infertile or hard to work, or when the surface soil differs sharply in character from that underlying it, the cuts should be kept shallow.

Stakes. Stakes set in a square grid at one hundred foot intervals, and on high and low spots, are used in measuring the original surface and for marking the new grade. One or more bench marks are set outside the grading area.

The new grades are marked on the stakes in any convenient manner. On fills, time may be saved by tying strips of cloth on grade lines to enable operators to see them without getting off their machines. Where soils are loose, two stakes may be used to advantage—one hammered down to ground level, the other left to project two or more feet. Cut and fill are figured from the top of the lower stake and marked on the upper one.

Clearing. Much of the growth in arid regions is of light and brittle character which breaks up during grading and mixes with the soil, and has value as a binder and a source of plant food that is more important than the slight difficulties it causes during finishing. This group includes the various kinds of sage, tumbleweed, and many of the smaller cacti.

However, larger shrubs and trees such as mesquite, greasewood, and acacia, the presence of which often indicates good soil, are tough and deeply rooted and their removal requires heavy machinery. In thick stands of these plants clearing is more expensive than grading.

Such growth can usually be piled and burned immediately after removal. The leaves and sapwood are resinous and the dry soil sifts out of the piles so that they burn readily. Heavy trunks are more difficult to ignite, and if only a few are present it may be cheaper to haul them to a dump than to tend the fire long enough to consume them.

Savings may be effected by cutting the trees flush with the ground wherever the fill will be deep enough to permit tilling over them. However, this is not recommended as it will prohibit the future use of pan breakers or other deep tillage tools, and will add greatly to the expense of installing underdrains if they should become necessary. The same objection applies to burying logs in the fills.

Wind Damage. Clearing and grading should not be started until irrigation water is available. The native vegetation, even when very sparse, has some power to break the wind and hold the soil. The weathered ground surface usually has a crust which resists wind scour. These natural protections are destroyed by the work, and unless water can be put on and a holding crop started immediately, the best part of the soil may be blown away or piled into dunes that may be more costly to level than the original surface.

Wind damage during the work may often be avoided by choosing a season in which windstorms are infrequent. If this is not possible, the final leveling and planing should follow immediately behind the rough grade, as a perfectly smooth surface is much more resistant to scour and dune formation than one having ridges or tracks of machinery on it.

If such a planed surface becomes roughened by wind, it should be replaned before the next storm, and kept flattened until a crop can be grown.

Machinery. Dozers are used to clear, to take the tops off ridges and dunes, to bevel steep slopes, and to fill in pits; for cut and fill work on short pushes, and for pusher work with pans.

A drag leveler can be used to smooth out rough spots wherever it is possible to walk the tractor over them. It can transport soil long distances, although its efficiency diminishes rapidly over two hundred feet. As compared with the dozer, it has the

advantage of making a wider cut, with little tendency toward scalloping, and has a greater transporting capacity and speed. As compared with pans, it has greater stability against overturning, smooths a wider area with each pass, cuts down and fills more quickly, and can be dumped promptly if the tractor gets stuck. It has a smaller transporting capacity and generally will not make as smooth a grade.

On any large area, the bulk of the dirt moving is most efficiently done with scrapers. Because of the width of most of these grading jobs, and the small slope of the land, these can be used in almost any pattern preferred by the foreman or operators.

Grading. One technique is to produce a rough finish grade in the high corner of the field and to expand this grade as continuously as possible. Where necessary, spot grading operations are done beyond this area in order to secure fill or to dispose of surplus.

Economies may be effected by loading the pans toward adjoining depressions so that the soil pushed along in their efforts to load will fill them. If the soil is very loose, this may be more important than loading in the direction of the dump, but it is often possible to do both.

Fills are usually made in thin layers in order to get maximum compaction from hauling equipment, as rollers are seldom used. Tamping rollers will produce a more permanent grade where fills of more than a foot or two are required, but close competition for the work may not permit the necessary increase in price.

Rough graded sections may be settled by flooding before doing finish work.

It is often possible to keep the short range equipment, dozers and drag scrapers, working all the way through the job if the area contains a number of adjacent humps and hollows. The drag level can also do the light finishing more economically than the pans.

Finishing Off. As soon as any considerable section is rough finished, grades are re-checked and additional stakes may be placed. These can be on fifty foot centers both ways, or fifty feet one way and a hundred the other, or at the intersection of diagonals across the original squares. Any changes of grade necessary at this stage can usually be made by the drag level.

If a small error has been made in balancing cut and fill, the gradient in the lower part of a field or bench may be increased or decreased slightly to change the quantity needed to balance. Large errors may require lifting or lowering the whole field, or one of its benches, or making arrangements for disposal or borrow outside the plot.

When the entire field, or a large section of it, has been brought as near the finish grade as is practical, all stakes are removed and the job finished with a land plane. This will flatten ridges and hollows around stakes, plane off spill windrows, piles, and track marks, and even off local inaccuracies at hitting the grade.

Planing also serves as a maintenance operation and is sometimes repeated after each harvest.

Distribution pipes are usually laid immediately after completion of leveling. Ditches should not be dug until the pipe is on the job, as drifting soil can fill them very rapidly. It is usual to lay and cement the pipe, to partially cover it by hand, and to allow it to cure. This fill is removed by hand where standpipes are installed. The ditch is then backfilled and graded over by machinery.

IRRIGATION DRAINAGE

Alkali. All soils contain some salts, both in soluble and insoluble forms, and these are necessary for plant growth. In rainy climates the soluble salts tend to be leached out of the soil and carried away in underground water about as rapidly as they are

formed from insoluble forms by plant action or weathering.

In dry climates where there is not sufficient rain to leach them effectively, they accumulate in the soil, accounting for the great richness and productivity of the land. However, in flat low areas and some other places the salts, then known as alkali, may be concentrated so heavily that they kill plants instead of aiding them. Alkali may also appear as a surface crust where ground water comes to the surface and evaporates.

Underground Pools. Where soaking rains are rare, natural underground drainage tends to be poorly developed or nonexistent. If such an area is irrigated, water absorbed in excess of that required by the crops will accumulate in a stagnant underground pond whose top may rise close to the surface.

This water will dissolve minerals on its way down and while lying underground, and usually becomes so alkaline that it injures or kills plants which absorb it. If it does not become loaded enough to do this, it still may injure plants by drowning their lower roots. Also, when the water table is near enough to the surface so that capillary attraction will lift it to the surface —a short distance for light soils, a long one for heavy—its evaporation will form an alkali crust.

When such a stagnant or semi-stagnant pool forms, the land above it usually becomes unfit for crops; and even if irrigation is stopped and the water slowly drains away, the alkali deposits in the soil may render it unusable. Artificial leaching would re-establish the underground water.

Drainage. The area can usually be put back in production by the installation of an adequate system of drains. These will serve to lower the water table below the trouble line, or to give the water enough flow toward the drains so that it will not stay in the soil long enough to become alkaline.

Such drains are preferably deep, six to seven and a half feet being usual, and spaced from 75′ to 800′. Close spacing is for impervious soils, wide for pervious ones. However, for sub-drainage purposes, the porosity of the soil cannot be judged from casual inspection, or even by analysis of samples. Heavy impervious clays often respond readily to tiling, because they are filled with fissures, either open or sand filled, which conduct the water. Many really tight soils will not require drainage because of their refusal to absorb the irrigation water.

Some irrigated lands are composed of alternating layers of heavy and porous soil, which are in the form of lenses tapering to nothing on each end, so that natural drainage must move through both types of soil. Ditching cuts and drains the porous lenses.

The tile lines which do most of the work of draining are called laterals, and the larger pipe into which they empty is called the base line. Four or five inch laterals and six or eight inch base lines are usual. Sizes are ordinarily much smaller in proportion to acreage than in non-irrigated fields, but layouts are similar.

If the excess water is leaking from an adjoining canal, the intercepting drain should be placed parallel to the canal, at a distance of fifty to seventy feet. Water may leak under it if it is too close or too shallow.

It is best practice to lay all drainage tile on gravel, and under tar paper and gravel, as described in Chapter 5, as the effective life of the system will be many times that of plain tile. Since tiling is generally done in saturated land, a tile box should be used to avoid danger of cave-ins.

Leaching. After a field is subdrained, alkali can be leached out of it by repeated soaking with irrigation water. This dissolves the chemicals and removes them through the tile lines.

CHAPTER EIGHT

ROADS

ROAD TYPES

Pioneer Roads. Pioneer roads are access roads built along the route of a highway, pipeline, or other heavy construction project to allow the movement of equipment to and between different sections of the job. If such a road is required, it should be the first work undertaken; and any delays in cutting it through will slow the starting of the job and may keep men and equipment idle.

It is best to locate it sufficiently to the side so that it will not be blocked or cut off by the main work, and if it must cross the construction strip, it should do so where it is close to grade.

The importance of the pioneer road decreases as sections of the main road become passable for trucks, but it often retains at least emergency or detour value until the job is finished.

If it is to be used only for moving in equipment, it may be narrow, crooked, and steep for the sake of economy or haste. Specifications written, and the route surveyed or walked through for it, serve as guides rather than instructions, and the job supervisors are usually given wide latitude in altering them for the sake of speed or economy.

Pioneer roads are most often needed in mountainous and timber country where severe obstacles hinder cross-country travel. Where fill is available, trees are cut flush and the stumps buried; otherwise they are uprooted and the holes graded in. Topsoil is handled as fill.

Rock is avoided as much as possible in the layout of the road, and when found is often buried instead of blasted. If an excessive amount of rock must be moved, it may be economical to place the pioneer road in the route of the highway, as the cost of the separate blasting may outweigh the advantage of the independent road.

Grades follow the land contour as closely as possible. The maximum grade will depend on the use. Shovels, tractors, and lightly loaded trucks should be able to negotiate grades up to thirty percent, but serious delays can be caused by stalling of weak units, or as a result of skidding. Ten to fifteen percent grades are more practical.

Curves should be wide enough to enable the longest units to get around them somehow, and the machines in steady use should be able to make them without backing. Attention should be paid to the lane width needed, so that inside rear wheels will not run off the road. Width requirement increases with length of wheelbase and sharpness of turn.

The road width is determined by its intended traffic, construction problems, and haste. It is desirable that it be two lanes

wide, but this is often not practical. On steep slopes, two one way roads may be constructed, one above the other.

Two way traffic on one lane will require turnouts every two to five hundred feet.

Small streams are best bridged with corrugated metal culvert pipe and fill. Occasionally, bottoms may be hard enough to permit easy fording.

Fords are the most economical means of crossing larger streams. A soft bottom can sometimes be made safe by a rock fill. Its downstream edge should contain heavy boulders.

If a ford is not practical, multiple culvert pipe, log or timber bridges or trestles, or prefabricated steel bridges may be used.

Roads built for use in a dry season may be so constructed that they will be washed out when the rains come if the contractor believes they will have served their purpose by then.

The bulldozer, or angle dozer, is usually the primary tool for cutting a pioneer road. Methods are described in a later section.

In sidehill cuts, the road surface should slope down to the bank or inner side, and may also have a berm along the outer edge. This construction allows for fill settlement, reduces washing of the fill slope, and decreases danger of sliding off the road.

Drainage from the road surface and the hill slope is carried along the inside bank to culverts, or to outward dipping sections of road reinforced with rock or blacktop. Overhangs or sluices must be provided to carry the water across the fill.

One of the constructions used by the U. S. Forest Service is shown in Figure 8-1.

Access and Farm Roads. A pioneer road is an access road for each otherwise isolated piece of the job it services. However, the term access road usually means a road by which a whole job is connected to a highway system, and is generally used in connection with pits and dams.

The quality of construction is variable. If the project is small, or to be quickly finished, and no substantial amount of raw material is to be trucked in, or products to be taken out, rough pioneer construction may suffice. More often, it must be built as a haul road. Occasionally, a first-class highway will be required.

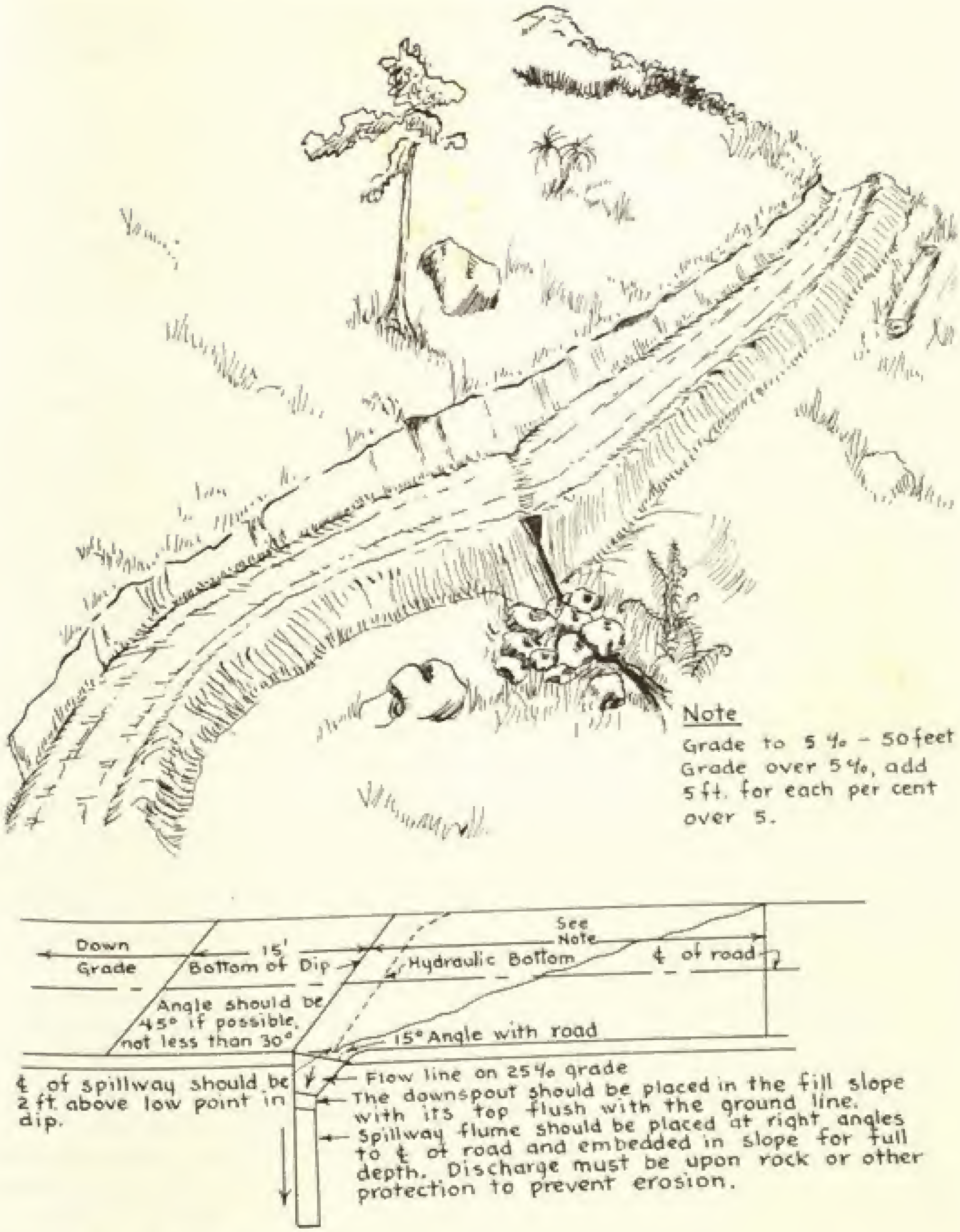
Farm roads are usually graded native soil, two lanes wide, with gravel, dirt, or other low cost surfacing.

Haul and Logging Roads. There is no sharp distinction between these two types. Both must carry heavily loaded trucks at a good speed, and are ordinarily located according to a favorable terrain, rather than property lines. The logging road is likely to be longer, to climb to much greater elevations, and, under modern lumbering practice, to be permanent. The haul road will carry a much greater traffic for a limited time, and then often will be abandoned.

As compared with the pioneer and access types, these roads differ in that grades are limited. Ten percent is the usual maximum for the logging road, and in haul roads grade is sometimes kept as low as three percent of climb in the direction of load movement. Culverts and bridge capacities are designed according to the period of use, and the comparative expense of large openings, or repairing washouts over smaller ones.

The long climbs needed on log roads in mountainous country are best ascended at even grades, which can only be attained by careful survey of possible routes. Where the direct distance along a valley wall is too short to provide the ascent at the required grade, the road may be run back into spur valleys instead of crossing them on trestles, or may ascend the slope in a series of switchbacks, or hairpin turns. The turns require a wide space, which, for economy, should be placed where the grade is flatter than ordinary, or where excavation will require minimum blasting.

These factors limit the route rather



Courtesy of U. S. Forest Service

Fig. 8-1. Hillside roadway

closely to that originally surveyed, although occasionally, if the contractor runs into unexpected difficulties, he can have the road shifted to avoid them.

The haul road seldom has long ascents and descents, but switch-backs and side wanders must often be used to get them out of a deep pit or over a ridge too massive to be cut.

Logging roads are surfaced with local

material where possible, from cuts or borrow pits along the road. Any fairly hard and porous material, such as gravel, desintegrated granite, or broken shale can be used, as traffic is ordinarily not long sustained. Haul roads may be oiled to control dust and speed traffic.

Trouble with snow or ice is minimized by locating on the north or east slopes of valleys.

Development Roads. Roads built for real estate subdivision vary in quality from the crudest pioneer type to city streets. Differences depend on the type of development, local regulations, value of land, capital available for improvement, terrain, and other factors.

Rural subdivisions are seldom regulated, but those in and near cities may have to have roads built to high standards. However, the developer may be allowed latitude in locating roads, or shifting them to avoid obstacles, to run cuts through banks of desirable fill or gravel, to change lot lines, or to obtain a more attractive appearance.

Subdivision roads may be financed partly by sale of topsoil, gravel, fill, and other surplus material. Construction costs may be reduced and swamp land reclaimed by using appropriate areas as dumps for quarry or factory waste, or garbage.

Garbage dumps should be kept compacted by bulldozer spreading in layers, and the garbage should be buried under fill daily, or at least as soon as it is brought up to grade.

City Streets. City streets are built to exact specifications, often under circumstances which do not allow maximum output from either machines or men.

All operations are likely to be impeded by traffic, which will probably require working the job in sections limited to a few blocks, and frequently to half the street width. Provisions must often be made to pass traffic on intersecting streets through the work. In addition to direct interference with work schedules, congestion will probably delay trucks and machines entering and leaving the job.

Removal of old paving is usually the first construction step. Tar or asphalt pavements, on gravel or stone bases, are usually dug direct by any size dipper shovel, skimmer, or a tractor loader. Occasionally they are hard enough to require breaking with a ripper, or removal by a one-yard or larger dipper.

A shovel can dig close to manholes, but care should be taken not to hook into them, or into a widened masonry base, as these are easily broken or crushed. Pavement chunks sliding up on the manhole cover may be thrown into the bucket by hand.

Concrete pavements are tougher digging, particularly if reinforced. They may be bonded to the manholes or their bases so as to require breaking away by air hammers, ahead of shovel digging. They break out in big slabs which are difficult to pick up in the bucket, and to dump out of a small or medium truck.

Soil beneath the pavement is removed with it to required depth. It may be native soil, or rock, dirt, or even garbage fill. It may be honeycombed with pipes and conduits that may belong to the city, or to various utility companies.

If the grade is to be lowered, some of the pipes may have to be dug in deeper. In any case, extensive repairs, enlargements, or relocations of piping is liable to be done between the removal of the old pavement and the laying of the new. This will involve a lot of ditching and probably considerable delay.

The paving contractor should see to it that backfill is thoroughly tamped in all ditches.

After the completion of underground work, all manholes, catch basin gratings, and other street openings are fixed to line up with the new pavement surface. Checking should be done carefully by instrument.

The subgrade is graded and compacted according to specifications. Because of interference with manholes, and the need for working in short sections, a large amount of handwork will probably be required.

Highways. Highways make up the bulk of the excavating contractors' road work. Modern standards of width, grade, and alignment require heavy cuts and fills in rough or rolling land, and grading and compaction of subgrades involve heavy work on any terrain.

Highways are built to exact specifications, although the engineer in charge is generally allowed some latitude in interpreting them.

Contracts may be let on a basis of a fixed price for a job; a fixed price plus specified extras, such as allowance for overhaul, rock blasting, slides, or other difficulties whose extent cannot be conveniently estimated in advance; or on a price per yard basis. Less frequently, they are constructed on a cost plus or equipment rental arrangement.

Highway jobs may be resurfacing or paving of existing roads, widening and straightening of roads, building a new road in the approximate location of the present one, building a new road which will run along or cross the old one only occasionally, or a totally new road crossing undeveloped country. There are of course no definite lines of distinction among these types.

A requirement of most highway construction is providing for continuance of traffic along any roads running along or crossing the job. This may be a controlling factor in job sequence.

Airports. An airport runway is essentially a very wide, short, straight road. It is usually located on the flattest land available, but deep fills are often required.

Banks of cuts must be graded back to very gentle slopes to avoid choppy air currents.

Borrow is frequently obtained from the glide areas at the ends of the runway. It is standard practice to cut away any ridges which might be hit by a plane climbing slowly off either end of the runway.

The runway may have a level centerline, crowned up from the sides slightly for drainage, or have a flat cross section and a longitudinal slope. In either case, drainage slopes are very slight, and the surface must be exactly on grade to avoid puddles.

Taxiways and plane parking areas are roads surfaced to an ample width to carry the wheels of a plane running on the ground. Additional areas on each side must be cleared and lowered to allow clearance for the wings.

Airport subgrades and pavement may have to exceed standards for heavy truck highways if maximum size planes are to be carried.

GRAVEL ROADS

It is not the purpose of this book to describe road surfaces or stabilized subgrades. However, surfaces of bank gravel and other low cost materials are so frequently required for haul, access, and other work roads, that a brief discussion is in order.

Bank Gravel. Bank gravel is a natural mixture of pebbles and sand. For road building purposes it should contain some fines that will act as a binder. Most deposits contain cobblestones and boulders.

Specifications for road gravel vary greatly. The following spread includes most of them:

Passing a 2″ sieve	80 to 100%
" 1″ "	60 to 100%
" ¼″ "	40 to 85%
" 10 mesh sieve	15 to 70%
" 200 mesh sieve (fines or binder)	5 to 25%

In general, gravels with over ten percent fines are not suitable for roads that will be subjected to freezing. Less than five percent

may lead to loosening up in hot, dry weather. However, an increase in the percentage of coarse particles will lessen the softness caused by too much binder. Variations in particle shape and material will also affect results considerably. Increase of depth may make up for weakness.

There is no consistent difference between the parts of gravel banks which are above and below the water table. Water levels were usually different at the time the material was deposited. However, there is very often a difference in color due to above-water oxidation of certain pigments.

Engineers frequently write ideal specifications for gravel which is not obtainable, and contracts are let to use practical grades on a price or availability basis.

Screened Gravel. Specifications may call for screening gravel to be used in the top course or in the full road depth. Maximum size stones may be limited to one, two, or four inch diameters.

Screening is desirable to obtain a smooth, easily worked surface, but it often involves wasting of an excessive amount of stone which could be worked into the road. The resulting loss of strength may affect the road stability, particularly in crossing soft or wet ground.

In general, most oversize stone can be eliminated during the spreading and grading processes at less expense than pit screening, except in patching work.

Crusher Gravel. Bank gravel which is short of pebbles and long on stones, may be run through a crusher to reduce the oversize to pebbles. The result may be superior to run-of-bank of similar size distribution because of the angular shape of the crushed pieces.

Blasted rock which is run through a crusher, without separation of the product, will often produce a material similar in size, distribution, and performance to the best of bank gravels.

Crusher gravel is usually more expensive than run-of-bank because of the extra processing.

Similar Materials. Any hard material which is broken into particles of the gravel size range may be used in its place. The breakage may be from blasting, rooting or digging, burning, or the effect of heat and cold. Such materials include soft limestone, fine blasted rock, scoria, clay, disintegrated granite and shale, cinders, and volcanic ash.

Rock from tunnels (muck) is particularly suitable for road work as the tight, heavily loaded shots cause fine fragmentation.

Cinders, ash, shale, and some scoria should be used with caution as they produce good immediate results but break down into mud or dust under traffic.

Preparing Subgrade. The subgrade should be finished as accurately as possible. Ridges or hummocks of subsoil which extend up into the gravel weaken it. If the subgrade is clay or silt, it is good practice to place a blanket of clean, coarse sand to interrupt capillary flow and add to road stability.

The subgrade should be compacted if it is practical to do so. However, temporary gravel roads are often put across wet spots that are not workable. Rock fill, or extra depth of gravel is used to make up for lack of subgrade preparation.

Cross Sections. Three cross sections in common use are shown in Figure 8-2. The feather-edge construction in (A) calls for

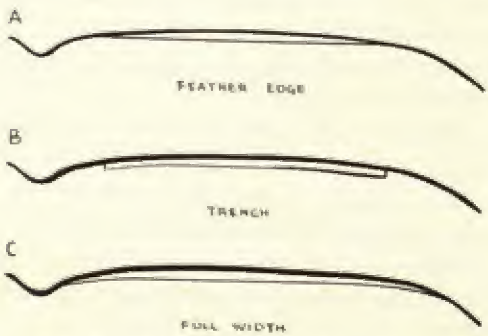
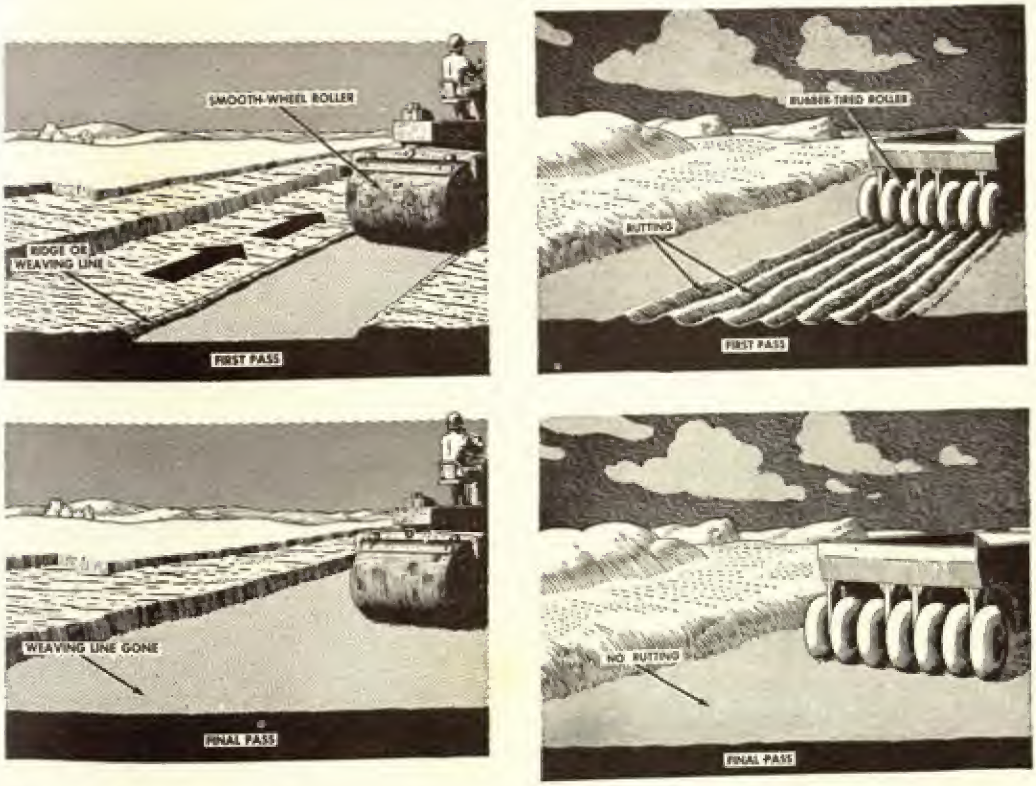


Fig. 8-2. Cross sections of gravel roads



Courtesy of War Department

Fig. 8-3. Subgrade compaction

a flat subgrade. Its advantage is ease of construction. Disadvantages include poor drainage of water out of the center gravel, deficient strength at the edges, and the necessity of blading fill from gutters or shoulders into the road during maintenance.

The trench section (B) provides center drainage and strength to the outer edge of the gravel. However, frequent bleeder drains through the shoulders may be needed to prevent water from ponding in the edges, soft shoulders may be a hazard in wet weather, and maintenance work will put dirt over the gravel.

The shoulders and gutters may be shaped before laying gravel, or the gravel may be laid and gutters then cut to obtain shoulder material.

The full width surfacing in (C) is the best construction, and is to be recommended wherever the price of gravel is not a controlling factor. It saves the trouble and expense of edging, provides hard shoulders and good drainage throughout the surface, and minimizes maintenance difficulties.

Placing Gravel. On good subgrades, gravel may be very thin, but it is the best practice to use six to eight inches compacted depth, and to spread it in two layers. On soft ground, the depth may be twelve inches or more. The greater part of deep gravel is usually in the bottom layer.

The best gravel available should be in the top layer. It should not contain many stones larger than one inch, or at the most, two inches in diameter. It should be coarse enough to resist the action of tire suction, water, and wind, and should have enough binder to hold it in dry weather, but not enough to make it sloppy when wet or thawing.

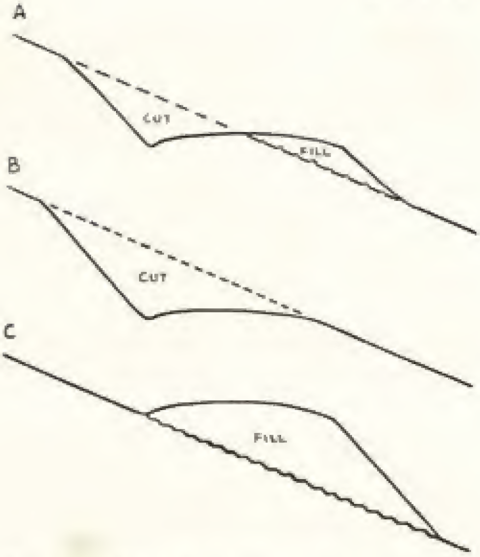


Fig. 8-4. Sidehill cut and fill cross sections

In the bottom, stones up to two thirds of the layer thickness can be tolerated. Clean sand without stone may serve if the top layer is thick and well bound enough to hold it together.

Gravel is ordinarily trucked in and spread by a dozer or grader. Occasionally, hauling and spreading can be done by scrapers.

Each layer should be thoroughly compacted by pneumatic tired or steel wheel rollers, or traffic. See Figure 8-3. A heavy steel roller will work back into the gravel stones pulled out by spreading work. Larger stones are thrown to the side to be taken away later. They are easier to remove if roughly piled rather than scattered along the edge.

The top layer may be dragged with a spike tooth harrow to turn out stones that might interfere with grading.

Minimum crown is 4″ for a 20′ road, 6″ is more satisfactory.

SIDEHILL CUTS

In hilly or mountainous country, roads are largely notched into slopes so that the land rises from one side of the road and dips away on the other. Such a road may be constructed by digging on the high side and using the spoil to build up the low side, as in Figure 8-4 (A); by cutting only, as in (B); or, less commonly, by building a shelf of fill as in (C).

Difficulties of design, excavation, draining, and stabilizing increase rapidly as hill slopes become steeper.

Stripping. Removal of topsoil, stumps, and logs may or may not be required. This matter will be decided by the job specifications, or by the judgment of the engineer or contractor.

In general, stripping of topsoil becomes both more difficult and less important as the slope increases, as deep cuts in steep hills increase the proportion of subsoil in the dirt moved.

When stripping is required, the topsoil can most economically be pushed straight downhill by dozers to form the toe of the fill, as in Figure 8-5 (A), or a windrow below it, as in (B). Such a windrow may be reclaimed after the road is built to cover the slopes.

If the hill is too steep to back up, the dozer may be equipped with a towing winch, and the line anchored above the work so that it can pull itself up the slope. It may also be helped by winch or direct pull from a tractor above it, or by a line around a pulley anchored above it to a

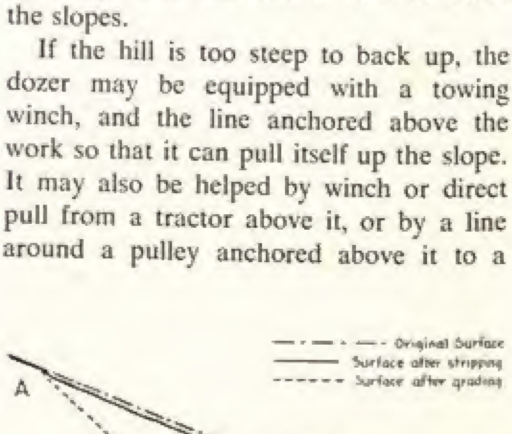


Fig. 8-5. Topsoil stripping

tractor on its own level or on a lower one.

Loose stumps can be used in pioneer road fills but are unsuitable for highways. Their use in intermediate classes of roads will depend on job conditions, the estimated useful life of the road, and the rate of decay of the stumps.

Logs placed at the toe of the fill are useful in catching rolling boulders and checking slides. These, or more elaborate precautions, are often required to protect roads or structures below. They may be held by their own weight, by resting against stumps, or by cables and anchors. They may be used as temporary expedients in most work.

Stumps left intact in steep fill areas may serve to prevent the completed fill from sliding downhill as a mass. Specifications often permit leaving them if they will be covered two or three feet deep.

If a sidehill is cleared and stripped, the areas to be filled should be plowed or roughened across the slope to reduce the danger of slides.

Dozer Digging. If the side slope is gentle, the road shelf may be cut by pushing downhill. Steeper slopes may be started in the same manner and finished by working along the roadline, as in Figure 8-6.

In general, when the upper bank becomes so steep that the dozer cannot back up it without assistance, it is more economical to work from the side. However, if the line of cut is interrupted by rock ribs, which are not to be blasted until the softer parts of the road are made, a dozer with a helper cable may be used to cut benches in each section, at least long enough to permit it to start a sidecasting cut.

Pushing from above, where practical, is faster than sidecasting.

Sidecasting. The standard method of notching a steep sidehill is sidecasting with a dozer. A wide track, close coupled dozer with a blade that can be tilted to cut low on the uphill side is most efficient. An angling blade, set with the uphill side low, and angled to cast down the hill, is useful, particularly in light soils and shallow cuts. The advanced position of the blade may make it difficult to turn with heavy loads.

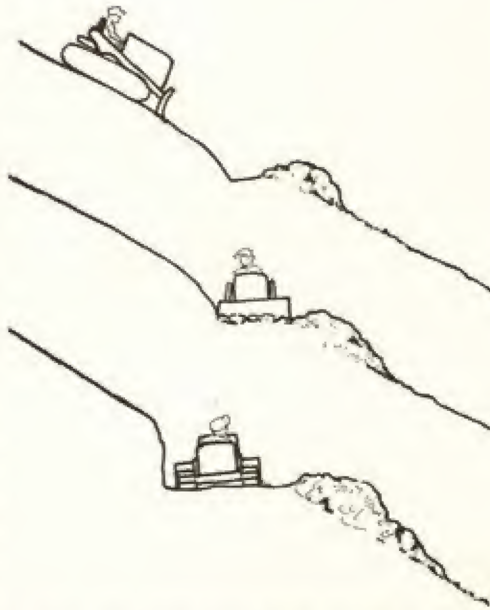


Fig. 8-6. Starting sidehill cut with dozer

A non-tilting bulldozer blade, or a shovel dozer bucket, requires special care in preserving a counter slope.

Work is started near the upper slope stakes at a spot naturally or artifically level enough to permit the dozer to work parallel with the road center line, at the upper edge of the cut. A blade full of earth is dug along the upper cut line, then the blade is lifted and the machine turned downhill at the same time. After dumping, the dozer is back until parallel to and touching the upper line, and another scoop dug and swung downhill.

One or several layers may have to be dug in one spot to obtain enough fill to build out the shelf wide enough to carry the dozer. Steeper slope, more passes.

The blade is raised sufficiently during the dump to keep the fill higher than the cut so that the notch will slope oppositely to the hill. This keeps the dozer tilted for efficient cutting, allows for compaction

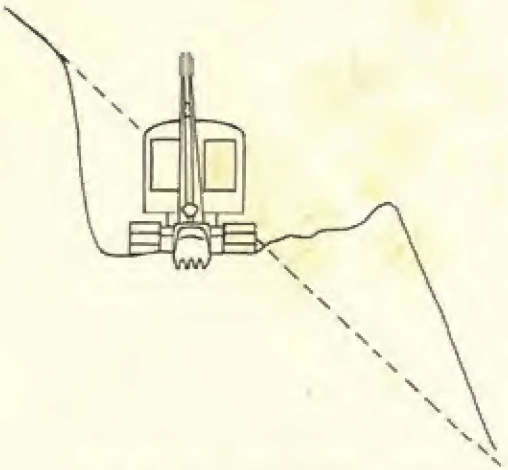


Fig. 8-7. Sidehill cut with shovel

of the fill when it is walked on, and also provides the proper cross section for a pioneer road.

When the shelf is wide enough to hold the dozer, further procedures are varied to suit the slope, the soil, the machine, and the operator's preference. The cut can be lengthened to the end of the slope, then cut in successive layers to grade and width, or it may be developed to full size in a single cut.

Layer cutting involves more rehandling of the dirt, as the loads dropped from the first cut are moved again as it is deepened. However, it is easier for a dozer to make shallow cuts, and the angle blade sidecasts most effectively, and puts minimum strain on the tractor when the cut is light.

Deep single cuts make it difficult to trim the bank and may have to be avoided for that reason.

Belt Loaders. Once a cut of sufficient width has been made between two areas that are wide and level enough for turning, a tractor-drawn belt loader such as the Euclid, or a self-powered unit mounted on a grader, can be used for widening and deepening the cut by sidecasting.

It may be necessary to follow the machine with an angle or straight dozer to grade off the spoil.

The belt machines ordinarily develop the cut in only one direction and deadhead back.

Dipper Shovel. The dipper shovel can be used instead of a dozer for notching a slope. It can usually do the rough work in one trip, as in Figure 8-7, but if the bank must be trimmed or the cut is very deep, it may be done in layers.

When the width of the cut will allow it, it is good practice to keep the shovel on its floor rather than with one track on the fill. For narrow roads, a part swing shovel, or one with a short overhang in the rear, is desirable. The cut should be kept sloped into the bank to keep the weight off the edge.

The fill is kept higher than the cut, particularly if used for footing. Poles or platforms can be used for extra support under both tracks, or under the outside track only.

When the ground is soft or wet, the slope very steep, soil layers slope with the hillside, or smooth bedrock is just under the cut, the smallest shovel which can handle the digging should be used. The weight of a large machine, together with the vibration of its work, may cause a slide.

Shovel spoil can most conveniently be sidecast, but can be loaded into trucks backed up to it. If the road is long and narrow, trucking out all the spoil will be very slow work.

Rock exposures along the road line should be blasted as a shovel cannot be readily moved up and down steep slopes to bypass them.

Use of a shovel is indicated when soil is too soft or rocky for effective dozer work, when cuts are deep, and when spoil is to be used at a distance.

The work is ordinarily left rough to be finished off by a dozer or grader.

Side Cuts. When the notch is to be largely or entirely a cut and the spoil is to be used nearby on the job, dozer side-

casting is used only until the shelf is of ample width to hold the machinery. The material is then pushed or carried along the shelf to the fill area.

Big dozers can be used for pushes up to two hundred feet on the level, and farther downhill with fair efficiency. When the cut is too narrow to allow machines to pass each other, their production can be stepped up, at some additional cost, by using two or more dozers in relays. One, working from the back of the cut, will push a load part way to the fill and spread it a bit in dumping it. The dozer below it will back over the heap and push it to the end of its beat.

Scrapers. The possibility of using scrapers should be considered. Their use on short runs is discussed later under Intermediate Hauls.

Tractor-drawn, full trailer scrapers are difficult to back, so in a narrow road they require an additional road to bring them back from the fill. This may have to go back to the beginning of the hillside, or enter it at some intermediate point. In either case, the scraper travel is apt to be much longer than that of the bulldozer.

A semi-trailer scraper can be backed up a narrow road, but only by a skillful operator. Travel distance would be the same as for a dozer, and production should be very much greater in proportion to power. However, only one scraper can be used conveniently until turnouts can be provided.

If some spoil is being sidecast, and some hauled away, a dozer can work on widening and serve as a pusher.

In the first stages of enlarging a notch, it may be difficult to keep the road sloping into the hill because of scrapers sinking and gouging into the loose fill. This pitch may be preserved or restored by running a grader or an angling dozer close to the wall, and casting out. As the cut widens and enters solid ground for its full width, it will become possible to keep it trimmed on the bottom by proper manipulation of the scrapers.

Some scrapers have an adjustment for tire wear which permits raising or lowering one of the rear wheel sets. Such a machine may be set to cut low on the inside during the pioneer stage of the cut.

When a steep hill contains boulders, stumps, or ledge, sidecasting is to be preferred to hauling, and dozers will probably be both safer and more economical than scrapers if short or medium hauls are required.

Compaction. When a wide road is notched into a hillside by cut and fill methods, it may be difficult or impossible to compact the fill if it is sidecast.

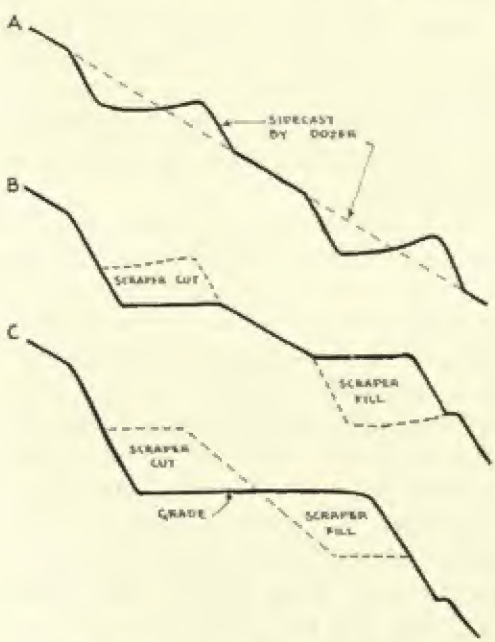


Fig. 8-8. Parallel cut and fill

If compaction is required, two pioneer notches may be made, as in Figure 8-8, at the top and the bottom of the cut. Scrapers are then used to cut the top down and build the bottom up. Compaction of the fill can be handled by rollers following the scrapers, until sufficient width is obtained to permit them to pass the scrapers on the

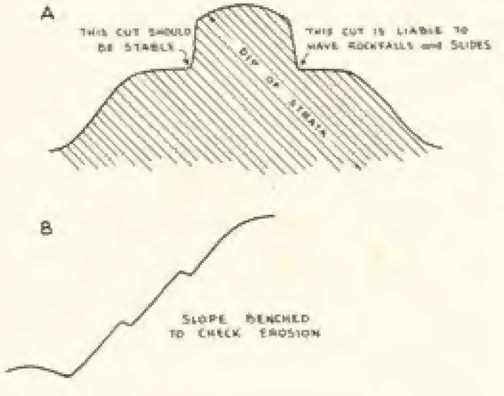


Fig. 8-9. Slope stability

fill, after which they can operate in both directions.

BANK SLOPES

Angle. The angle at which bank slopes will stand in cuts and on fills, is an important factor in the cost, and sometimes in the feasibility, of sidehill construction. It is also a limiting factor in the depth of through cuts.

It is desirable to keep these slopes at less than the natural angle of repose of their material, as shown by local examples, or laboratory tests. However, if the hillsides are at or near this angle, the cut wall must be substantially steeper to avoid excavating tremendous yardages. Also, a fill slope must be steeper than that of the sidehill on which it rests if it is to support a road.

Stability. A slope is subject to the influence of gravity and possible pressure of ground water which tend to cause sliding or caving. It is also subject to surface erosion, from running water, wind, and alternate freezing and thawing, or wetting and drying. Weathering causes changes in particle size and composition.

Resistance to gravity slides is a function of particle size and shape, stratification, and binding by natural cements. Water, if present, has the least effect on soils pervious enough to allow it free passage, and coarse enough not to be eroded.

Direction of dip or rock or soil layers may be important. See Figure 8-9 (A).

Long slopes may be benched, as in (B), to break the flow of surface water. Benches are stabilized in the same manner as diversion ditches.

Slopes can be stabilized by growth of vegetation. Most types will provide surface protection, and types with deep or interlocking roots may hold against some internal pressure as well.

Artificial protections include supporting walls, drainage systems to intercept or remove ground water, and fences to catch rolling pieces.

Walls may be of masonry, interlocked concrete, or metal bins. Strength of the last two constructions depends on their being filled with coarse, pervious fill. Any of these must rest on a solid footing that can resist both weight and thrust.

Logs can be used for temporary retaining walls and to catch boulders rolling during work.

Drainage. Freshly worked embankments should be protected against surface water flowing from adjoining ground. In cuts, a diversion ditch is usually dug a few feet back from the upper edge. Such a channel may require protection against erosion, to prevent it from developing into a gully that would damage land below it, and eventually break out through the bank.

Such protection may include establishment of a strong sod, construction of a series of check dams, paving with resistant materials, diversion of some of the natural drainage at higher points, or use of discharge flumes down the slope.

If the slope is threatened by softening or washing by ground water, subdrainage may be required also. Land tile may be laid under the surface channel if its floor is impervious enough not to allow excessive surface water to enter the tile. Underdrainage may be required in the gutter at the foot of the slope, and in or behind wet

spots in the slope to catch the seepage.

Fills usually have less drainage across them, but because they are not as well bonded together, they are more subject to surface erosion than cuts. Water may flow onto them from the road and from slopes above the road. They can be protected by berms along the outer edge of the road shoulders, which will prevent water from going down the side of the fill, except at points protected by pipes, flumes, or pavement.

Fills which are built on sidehills have a tendency to slide along the old surface, unless it is well roughened. Leaving of stumps and boulders, roughening by plowing, or placing of subdrains to stop seepage of water along the joint, are common methods of reducing this danger.

Any soil, whether original bank or fill, which rests on smooth steep rock slopes is liable to slide. The most important step in preventing slippage is diverting ground water moving down the surface of the rock.

Grading. Cut slopes may be practically vertical, or as low as 1 on 6. Fills are seldom steeper than 1 on 1½.

Many highway side slopes are so steep as to require special techniques in trimming them. For moderate angles, a wide track bulldozer may work the slope in horizontal strips from the top down, as in Figure 8-10 (A). Steeper grades may require the diagonal movement shown in (B). Use of graders on moderate side slopes, or dozers on very steep ones, may be made safer by cabling to another machine moving parallel to it on the top of the bank. Two cables are used attached to the front and rear of the lower machine.

It is not safe to operate unsupported heavy equipment along slopes which contain rocks, soft spots, or frozen ground.

Planting. The best protection for a dirt slope is a good cover of vegetation. Grass, weeds, bushes, and trees are all effective controllers of erosion. The type selected will depend on the locality, soil, and season.

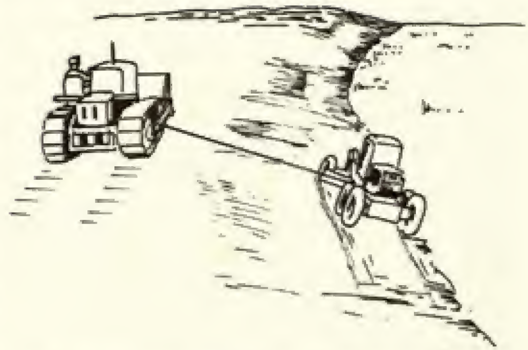


Fig. 8-10. Finishing a slope with a grader

On most jobs, it is necessary to place a layer of topsoil over the fill or exposed earth in order to get a good growth. Occasionally plants will grow well enough on raw earth, or with the aid of some lime or fertilizer.

Deep topsoil is favorable to growth but it may discourage plants from rooting into the subsoil, and absorb too much water so that it will slide off during rains. For this reason, and for economy, topsoiling of steep slopes is usually limited to a depth of two to four inches.

The fill surface should be roughened so as to bond with the topsoil. A sheepsfoot or tamping roller is one of the best tools for accomplishing this. If the slope cannot be worked, the roller may be operated by a dragline at the top. The drag cable is used to pull the roller up and to let it down, and the walking of the shovel moves it along the slope.

Topsoil may be pushed up a slope from stockpiles at the bottom, pushed down it from piles trucked to the top, or distributed over the surface by a clamshell working from either top or bottom, and the resulting piles shoveled or raked out by hand.

Fresh spread topsoil gullies readily and should be protected. A layer of hay or straw, mixed into it by a tamping roller, is probably the most satisfactory treatment. The hay should be well cured, as rapid de-

cay would make its useful life too short. It is apt to absorb so much nitrogen from the soil as to interfere with growth of seedlings. Use of barn straw that contains some manure, or adding nitrogen fertilizer, cures this difficulty.

Some hay and straw contains enough grass and weed seeds to establish a good cover. Other types are deficient and require that the ground be seeded. Seed can be mixed with water and sprayed onto slopes.

On small areas, topsoil may be held by adding straw, and holding it with chicken wire firmly pegged down. Horizontal wood slats are sometimes used. Placing and tamping cut sod in drainageways, in horizontal strips on slopes, or on the whole surface, is very effective but the cost is high.

Rock Faces. Rock cuts can be left with very steep or vertical faces, and occasionally are allowed to overhang. Such faces usually cause a hazard of rock falls to the pavement, but the expense of cutting rock back to completely safe slopes can seldom be justified.

Some rock formations tend to break up into gravel or small stones at the face because of temperature changes, and will at times subject the road to an almost continuous bombardment. Such faces should be cut back sufficiently to permit a wall or fence to be put beside the road, with space behind to catch falling stones.

More massive cliffs may present the danger of occasional falls of larger rocks or of whole sections. These may be checked in the danger season by a man with a bar, supported by a rope held at the top. Loose pieces can be pried out.

Long expansion bolts, similar to those used to secure tunnel roofs, can be placed to fasten a whole slope into a solid and safe unit. They are particularly efficient in shale beds parallel to the slope.

Vegetation tends to break up rock faces, so artificial planting should not be attempted.

THROUGH CUTS

A through cut has a high wall on each side so that little or no material can be excavated by sidecasting.

If it is on a sidehill, one edge will be higher than the other. The part of the cut which is above the low wall is actually a sidehill cut, and may be handled as one or as a through cut.

Through cuts are seldom used in building pioneer roads, except where borrow is needed to cross a ravine. When roads are narrow, and the sharpness of curves is not an important consideration, sidehill work is faster and less expensive.

SCRAPERS

Scrapers are the standard tool for alternating cuts and fills, where the soil is soft and fine enough for them to work, or can be made so by tractor drawn rippers, and the haul is too long for dozers.

Preparation. The first requirement is to smooth over the cut and the fill areas so that scrapers can work them. This is usually a dozer job. The ground is cleared of vegetation, potholes are filled, gullies broken down and ramped over, sharp ridges beveled off, side slopes notched, and turning places graded off.

It is not absolutely necessary to prepare the whole area in order to have the scrapers move in. Their work can start on the high part of the cut and the low part of the fill, while the dozers are clearing and smoothing the balance of the area.

If the cut has a high side, it is cut to a passable driveway by straight pushing or sidecasting. The bottom of this cut is sloped oppositely to the hill.

If the hill is high in the center of the cut, the hump is graded off sufficiently to afford good footing for scrapers.

It is sometimes economical to make small fills in areas which are to be lowered, and small cuts under future fills in order

Fig. 8-11. Slope too steep to work

to smooth out working areas quickly.

When a dozer is not available, a scraper can smooth moderately rough ground by driving through it with the knife held low enough to cut off the bumps and high spots. If the tailgate is held near dumped position, it will act as a dozer blade, and spoil will be dropped into the first hollow. If the gate is held partly or entirely back, the cuttings will accumulate in the bowl to be dumped in larger hollows or carried to the fill.

Turnarounds. The location of the turnaround in a narrow one-way cut is affected by the difficulty of making it. For efficiency, it should be slightly across the hillcrest from the fill, so that the scraper can be straightened out to load just before it crosses the crest. However, the digging will work the crest back and destroy the turnaround quite soon. It may therefore be wise to locate it well back from the crest.

Whenever possible, a turning place should be wide enough for the machines using it to get around without backing. Space requirements vary greatly in different sizes and types of scrapers. Time may be saved, and accidents reduced, by providing more space than the minimum requirement, particularly for sharp-turning models.

Cutting Ridgetops. If the slope up from the fill is too steep for the scraper to climb, it may be broken down into a ramp by dozers, or the cut made with shovels.

If the slope away from the fill is too steep for scrapers, as in Figure 8-11, the top can be lowered by the combined work of scrapers and dozers, as shown in Figure 8-12. Full trailer scrapers will dig across the cut as they turn, as in (A). Semitrailers can be backed up to the edge, as in (C), and if a snatch tractor is available, can be backed over it. Digging is then done straight toward the fill.

The undug lip left by the first method is pushed over the edge by a dozer, as in

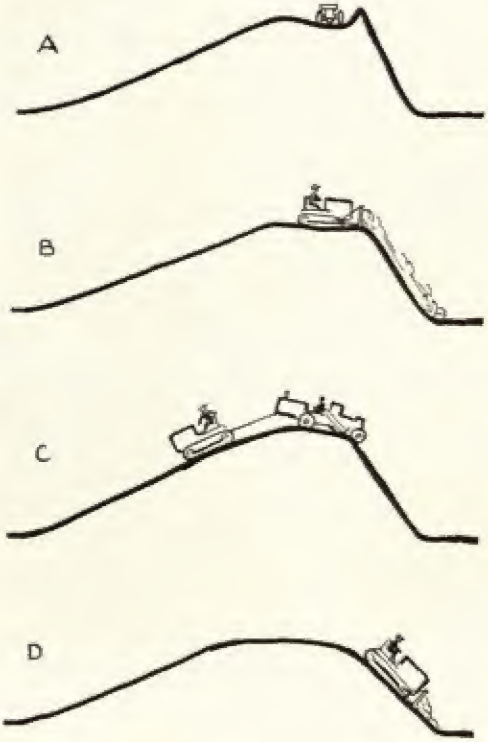


Fig. 8-12. Breaking down steep slope

(B). This filling, and the cutting into the slope, will extend the floor and allow scrapers to work farther back.

Eventually the bank will be lowered sufficiently to make it practical to break it down with dozers (D), so that scrapers can go through to dump on the far side, or turn to continue hauling in the original direction.

Digging Patterns. Scraper work patterns should be arranged to allow for as many of the following as possible:

1. Digging downhill.
2. Digging in the direction of the work.
3. Utilization of pushed soil.
4. Efficient turns with minimum deadheading.
5. Start cuts at high points, and fills at low ones.

Direction of Digging. A favorable grade increases the speed and the effectiveness of loading, and reduces wear on the power units. The advantage becomes more marked as the downgrades get steeper.

Figure 8-13 shows three ways to make a deep scraper cut. (A) is inefficient because the downgrade is used in transporting where little power is required and does not assist the digging. (B) takes full advantage of the downgrade but may create an inconveniently sharp angle at the beginning of the cut.

In (C) the digging is started on the upgrade, just before the crest. The power requirement for the first few yards is small as resistance increases with load. The machine is rounded into the downgrade for the bulk of the load. This keeps the crest cut down without sacrificing much of the advantage of the slope.

Digging in the direction of the work is desirable. A loaded pan moves slower, wears more, uses more fuel, and may be less stable on turns than an empty one. If the load is picked up heading toward the fill, it is able to take the shortest path to the dump, and to make the turns and the longer run beween them empty.

However, there is often sufficient reason for digging away from the dump. Digging downhill is more important than direction. Occasionally a pusher can be best utilized if scrapers are loading in both directions, which, in a single cut and fill, would re-

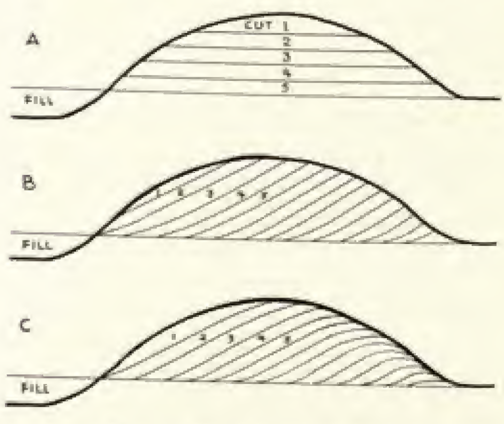


Fig. 8-13. Taking off a hill

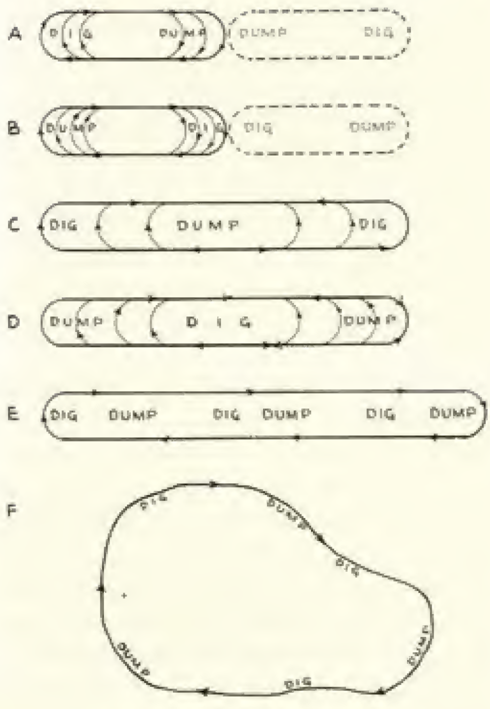


Fig. 8-14. Scraper patterns

quire about half the units load before turning to go to the fill.

Pushed Dirt. The scraper knife usually pushes some dirt ahead of it, the amount increasing with the size of the load. Loose material such as sand may be moved in considerable quantities. This is left in low piles when the bowl is lifted.

This dirt can be utilized to build up the fill where it meets the cut, by allowing the bowl to drag slightly until the fill is reached. However, dragging may cause a loss of speed which outweighs the importance of the dirt moved.

Care should be taken not to cut below grade at the junction with the fill unless it is necessary to make a ramp.

Turns. The time consumed in making a U turn with a scraper may vary from five to sixty seconds or more, depending on space available, ground conditions, type of machine, traffic, and operator. Fifteen seconds is a fair average.

Time consumed deadheading from the working area to the turn and back, may be considered part of either the turn or the haul, but it is better practice to consider it a separate part of the cycle.

On short hauls, turns and deadhead time have an important effect on production. As hauls become longer, their significance decreases.

There are four major patterns of scraper operation which are shown in Figure 8-14. In the first, (A) and (B), there are two turns to each dig-dump cycle, in the second, (C) and (D), one, and in (E) one half. (F), with no U turns, is only practical when a very wide area, such as a field or runway, is being graded.

When both cut and fill are wide enough for easy turns, the (A) and (B) layouts may be most efficient, particularly when work areas are long and tractor speeds low. The advantage is that the scraper can turn to start a new cycle immediately after digging or dumping. The length of haul can therefore be figured between the centers of mass of the cut and the fill, as the longer and shorter runs will average out.

The diagram and arithmetic in Figure 8-15 indicate the advantage of operating one cut with one fill under the conditions

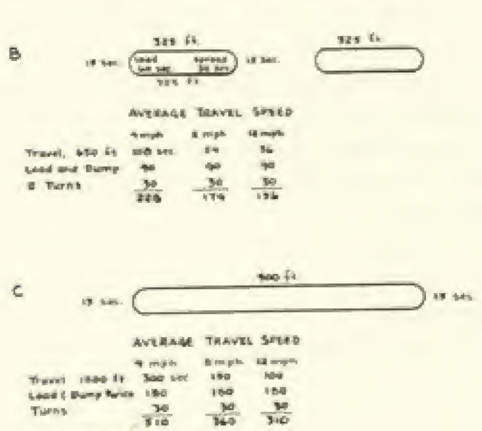


Fig. 8-15. Turns may save time

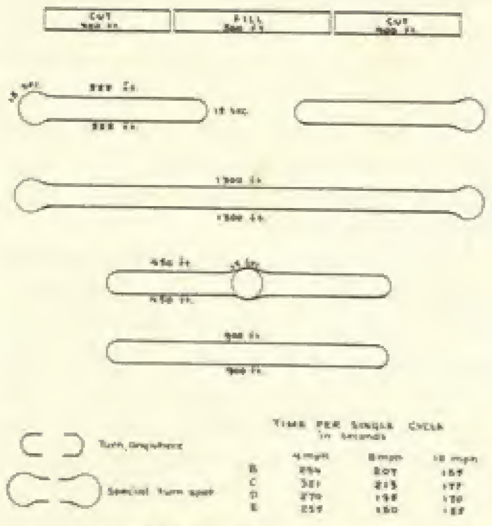


Fig. 8-16. Fixed turn patterns

outlined. It will be noted that the advantage decreases as tractor speed increases.

If turns cannot be made immediately at the end of the work, the time required to travel the average distance from the ends of spreading runs, and from the beginning of cuts to their turns, must be added to the cycles, as in Figure 8-16.

Through travel highway patterns, Figure 8-14 (E), have their greatest use where the graded area is too narrow for turns, and cuts and fills are rather short and closely spaced. Their efficiency depends on the extra time required for through travel, compared with that used for turns and deadheading.

These examples are somewhat oversimplified for demonstration purposes.

Intermediate Hauls. Some hauls are too short for normal scraper use and too long for dozers.

A bulldozer's production falls rapidly as length of haul increases. It becomes uneconomical somewhere between 100 and 200 feet on level ground, although it may be used for much longer distances. Because of complications of turning and distances required to load and to spread, scraper use generally starts at two to four hundred feet. These figures are for large machines. Small bulldozers lose effectiveness at lesser distances, and small scrapers are operated on much shorter runs.

Scrapers can often be used more efficiently on very short hauls than is generally believed. They can waste considerable time deadheading to turns, and carry undersize loads because of short digging runs, and still move much more dirt than a dozer.

When the fill is too short for proper spreading, part of the load can be carried around the turn and dropped on the way back to the cut.

Semi-trailer scrapers can be used shuttle fashion. The load is spread dumped, and the machine backed into the cut for another. In each pass some of the spoil will be moved, dozer fashion, in front of the knife, and dropped at the beginning of the fill.

Two-wheel drag scrapers, such as are used for land leveling, can be used shuttle fashion and in easy digging will move about double the load of a dozer blade. Large models are very wide so as to be inconvenient to transport and unable to work with other machines in ordinary roadways.

Working Down. Scraper cuts should be brought to a convex or crowned cross section. The outer slopes tip the scraper weight toward the bank so that it is less likely to ride up over hard spots at the edge, or to slide away from the bank. Irregularities appearing in the center are readily worked down by varying the angle of approach, but corrective measures taken near side slopes may damage them.

Scraper work on side slopes is simplified by first cutting a shelf with a dozer. If no dozer is available, the scraper can be taken uphill to the start of the cut, the blade dropped, and the scraper turned to dig along the upper cut line. The turn will cause the edge to cut deepest on the uphill side, and if done repeatedly, will level the

Fig. 8-17. Scraper pioneering a sidehill cut

digging area, or slope it oppositely from the hill. See Figure 8-17.

The cut is taken down in layers. The depth of slices will depend on the behavior of the soil. Loose soils may require a deep cut to force them up into the bowl. Tight ones do best with thinner slices which minimize cutting effort.

Increase of power applied to the blade permits taking thicker cuts, and fills the bowl in a shorter run. As the bowl loads up, the soil in it resists the upward passage of that being dug, and this added resistance may make it difficult to get a full or heaping load.

In heavy soil, mounting resistance may be counteracted by taking a thinner slice, or occasionally, by pumping. Loose soils such as beach or desert sand respond well to pumping.

Pumping involves raising and lowering the bowl in order to alternate deep gouging with shallow cutting. The shallow run builds up momentum, and the thick bite punches up through the load effectively.

The cut should be kept properly shaped as it is worked down, both in profile and cross section. Accuracy is necessary only at the edges, until a close approach is made to bottom grade. However, to facilitate rapid movement and easy loading, it is important to keep the pit from getting too rough or ridged.

Scraper cuts may parallel previous ones, as in Figure 8-18 (A), overlap, as in (B), or space and straddle (C). Straddling is often effective at getting good loads in tough or loose soil, as the digging resistance seems to be proportionate to the depth at the sides rather than the center; and the thick center punches its way up into the bowl.

Some soils cut to flat surfaces readily while others do not. Under some conditions scrapers can keep the cut floor in good condition; and under others it will be advisable to have a dozer or a grader to keep it

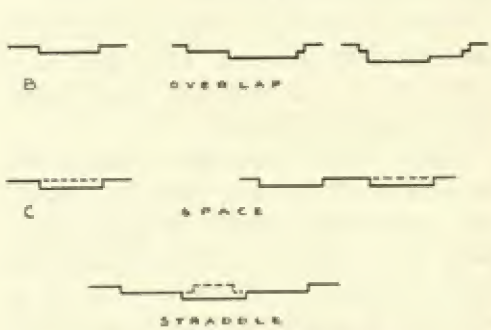


Fig. 8-18. Digging sequences

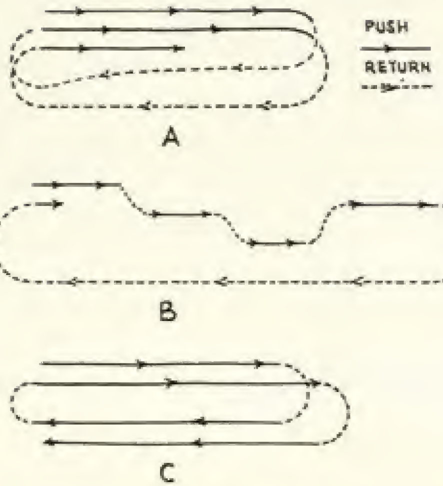


Fig. 8-19. Pusher patterns

straightened out so that the scrapers can concentrate on earth moving.

If bedrock is found in the cut, it may be advisable to have a dozer strip the overlying soil and push it out to be picked up by the scrapers. A scraper is more vulnerable to damage from contact with rock, and its loading will be slowed by any effort made by the operator to avoid such damage.

Pushers. When the tractor pulling a scraper does not have sufficient power or traction to load it fully and quickly, a pusher tractor may be used to assist it. The pusher, which may be a dozer with or without a reinforced socket in the blade center, or a tractor carrying a rigid frame and push plate, makes connection with the back of the scraper and pushes it through the digging run until it is loaded.

Most pushers are crawler tractors. Rubber tired units with four wheel drive do a good job, but lose efficiency more rapidly under slippery conditions.

Pusher plates are much cheaper, but are of more limited use. Their fixed height may make them unable to push certain pans, or at least to require a tedious mechanical adjustment before they can do so. On rocky or uneven ground, it may not be possible to apply the pushing power as efficiently as with a movable blade. They cannot be used to grade or clean up the cut in between pushes.

Snatch tractors may be used instead of, or in addition to, the pushers. These tow the tractor-scraper by means of a cable, chain or an automatic coupler. They avoid the pusher tendency to jackknife the scraper, but connecting and disconnecting are not as rapid, and it is not always obvious when the scraper is loaded and ready to take off.

Pushers are usually required by scrapers whose prime mover has rubber tires, and by oversize scrapers drawn by crawlers. They may be helpful to any size or type of scraper tractor combination in tough going, in short cuts, when time is at a premium, or if loading uphill cannot be avoided.

In short cuts, the pusher will return to the starting point after each shove. In long ones, it may push several scrapers before it reaches the end, when it will return to the beginning at high speed. In two-way cuts, it pushes both ways, with little idle travel.

There are several patterns of pusher loading which are in common use. The simplest, shown in Figure 8-19 (A), is for the scraper to drop its bowl, and the pusher to make contact, at the beginning of the cut. One tractor pulls and one pushes until the desired load is obtained. The pan bowl is raised, informing the pusher operator that he is not needed, if he has not already learned this from watching the load. The tractor scraper then shifts into a higher gear and departs.

The pusher returns to the beginning of the cut. It may make this move in reverse, or by turning and using forward speeds. The length of the cut and the relative speeds the machine can make in the highest usable reverse and forward speeds, determine which should be used.

If the next scraper gets in loading position before return of the pusher, it will start

to load itself, as it can pick up part of a load readily, and will thereby decrease the distance the pusher must come back in order to get behind it.

Another pattern, shown in (B), is suitable only for long cuts. After loading the first scraper the pusher waits for the next empty one to come up along side it, pushes that until it is full; pushes the next from its stopping point, and so on until the end of the cut is reached. The pusher is then turned and run back to the beginning of the cut to start another series.

A third system, which is useful where there are more scrapers than the pusher can readily handle, or where the dirt can be moved in two directions, is outlined in (C). Each scraper is loaded moving in the opposite direction from the previous one, so that the pusher need only turn around to be in position for the next push, instead of having to move back to a starting place.

A pusher should have as many scrapers as it can conveniently handle, but it is difficult to maintain a proper proportion because of changes in the length of haul. Two pans might keep a pusher busy on a very short haul, where a dozen might not work it steadily on a long run.

It is more economical to keep a pusher partly idle, than to have scrapers delayed for lack of one.

Where there are more units than a pusher can service so that one or more are waiting, and it is not possible to shift any to longer runs, it may be wise to have the more powerful tractors or those with the shortest runs to load without assistance, so that all can be kept moving, although with a smaller average yardage.

In many soils a level load can be obtained in a fraction of the time required to add a heap to it. It may be more economical not to insist on the heap, particularly if the haul is short.

Soil and siope conditions being equal, loading time and the size of load in a particular pan are determined by the power applied to it, regardless of whether that power comes from one, two, or three tractors. Ordinarily, crawler tractors are teamed with pans which they can load without assistance, where rubber-tired tractors pull units which are too large for self-loading.

However, when crawlers are to be used for long runs without heavy grades, much larger pans may be used, and loading helped by pushers or steep down grades. Lessened loading efficiency and cost of operating a pusher are more than compensated by the increased yardage on each trip.

Loading time may vary from a few seconds to several minutes.

Rooters. If the soil is so hard that scrapers will not load properly, or excessive pusher or snatch tractor power is required, rooters should be used. If the cut is not a busy one, a rooter may be towed by a dozer which also does pusher work and tidying up, although the attempt to combine these jobs can result in inefficiency in all of them.

One, two, or three teeth may be used. One will provide maximum power to penetrate and to loosen, but will process only a narrow strip. Two outside teeth will double the width of the strip worked, will normally provide coarse breakage, and, if equal penetration is obtained, will halve the number of trips. Three teeth provide the same width as two and will make finer lumps.

Large scrapers can often load coarse material better than they can fine, but less dirt may be carried in the same size load.

If the soil is plastic, the tractor should not walk on previously broken ground, nor should scrapers be allowed on it except to dig, as compaction may make the soil nearly as tight as before ripping.

Trimming Banks. Successive cuts are set back from the edge to provide proper slope. Scrapers will not cut vertical walls but will leave very steep faces.

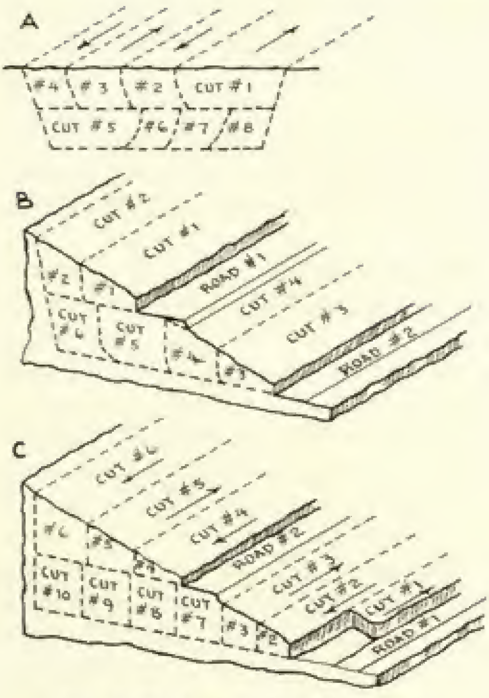


Fig. 8-20. Sequence of shovel cuts

Slopes between 1 on 1 and 1 on 4 are usual in soil cuts. If the scraper takes a six inch slice, a 1 on 2 slope would require each pass to be a foot inside the last. If 1 on 4, it would be spaced two feet.

The steps are best trimmed to a smooth slope by a grader working on the floor. The excess material is cut and slides to the bottom to be removed by the scrapers.

If trimming is done with a scraper, one rear wheel should be on the bottom, the other on the slope. If it is steep, the tailgate should be carried well forward so that loosened dirt will slide downhill rather than enter the bowl.

The cut should not be deepened so far between trimmings that the grader cannot reach all the steps. This is particularly important when the slope is so steep that it cannot be worked by machinery later.

As the cut deepens, new slope stakes are placed. They are often set from the originals with a string level, rule, and plumb bob. If driven in flush and marked with light sticks, a good grader operator can trim the bank without knocking them out.

Finishing Subgrade. The bulk of a deep cut can be made without staking except for the slopes. As it approaches bottom, however, grade stakes should be set, and digging done with sufficient care to avoid overcutting and resulting need for patch fills.

Good scraper operators can hit a grade within a fraction of an inch if the soil is smooth, but it is often better economy to have them run a rough grade and go on to other work while a grader finishes up. The grader will probably be required to cut and shape gutters, in any event.

The road, or the shoulders, are sometimes overcut to allow space for spoil from ditches. If this is not done, ditch cuttings may be windrowed on the road for later removal.

SHOVEL CUTS

Through cuts are made by dipper shovels and trucks when the original surface cannot be readily leveled for scraper operation, when the ground is rocky or wet, when the fill is too soft or too narrow for surface dumping, and when the haul is too long for scrapers.

In general, shovels do best in banks that are about as high as their shipper shafts. Soft, sliding banks of sand or gravel provide best digging when they are very high, but there may be danger from slides.

If the cut is considerably deeper than the favorable bank height, it may be taken in two or more layers or benches. On through cuts with a fairly level cross section, as in Figure 8-20 (A), the top is removed first. On sidehills there is an option of taking the top first, as in (B), or cutting the toe, then the top, then the floor of the upper cut, as in (C).

It is first necessary to build a haul road between the start of the shovel cut and the fill. Most of this may be already provided by highways or construction grading. It

should be wide enough for two trucks, although for short or small jobs, one lane with turnouts may be adequate. Slope up to the shovel should not be over fifteen percent, although in special cases, grades up to 35 percent have been used.

If no natural turnaround exists at the start of the excavation, and the grade is easy, trucks may be backed in at first. As excavation progresses, the pit floor will provide turning space.

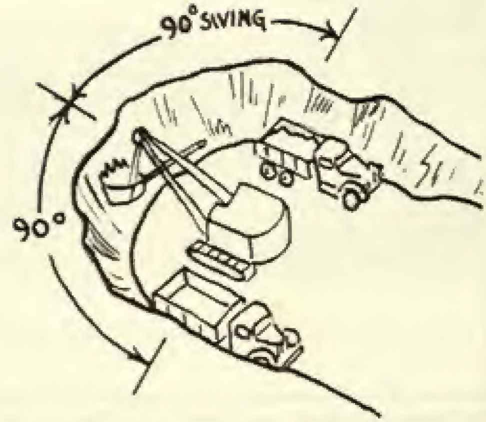
The roads in (B) and (C) are usually cut by dozers. They allow a rotary movement of one-way traffic past the shovel on its first cut on each level. They eliminate the necessity of turning at the shovel in cramped quarters. However, they may be too expensive or inconvenient to build.

When there is no through road, the shovel starts each level by taking as wide a cut as it can reach, as in Figure 8-21 (A), to allow space for two-way traffic, turning, and spotting two trucks at a time. Subsequent cuts are made about half as wide, as in (B), to facilitate loading and truck movement.

If the cut floor is soft, it is the best practice to use a dragline working from the top. However, if none is available, or the digging is too hard for it, the dipper shovel may work from supporting platforms and have a gravel, stone, or other road built behind it for the trucks. If it is working on the bottom level, the road can be left to facilitate surfacing work.

A busy shovel should have at least occasional help from a dozer, which can level the pit floor, clean up spilled dirt, get boulders out of the way, and assist stalled trucks. Even if the shovel can handle the operation without assistance, it will produce more if it needs only to dig.

A shovel cut should be started on the low side of the grade, and worked uphil so that it will drain. The floor should be shaped carefully to avoid excessive working over.



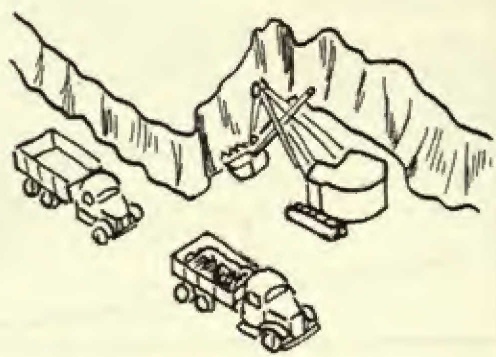


Fig. 8-21. Through and side cuts

STAKES

Figure 8-22 shows the names of various parts of the road structure and some of the stakes which serve as guides.

Centerline. The road is first staked along the centerline at 100 foot intervals. Each stake is called a station. It is marked on the front with the distance in feet from the first, or zero, stake. This figure is divided by a plus sign into station number and distance beyond that station. Five hundred feet from zero would be station 5 + 00.

Other center stakes may be set for closer control on curves or grades, or to mark changes in soil character, land slope, or intersections. A stake 545 feet from zero would be station 5 + 45.

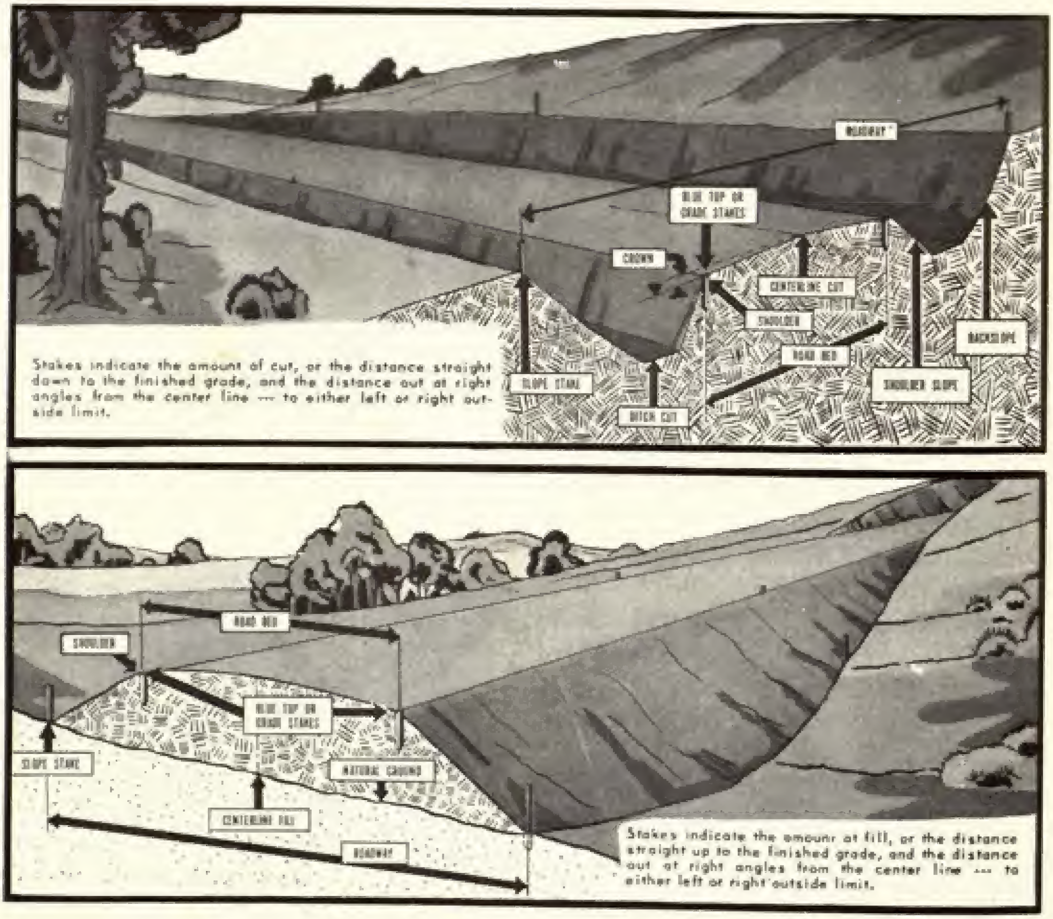


Fig. 8-22. Grade and location stakes

If the line should be extended to the other side of the zero point, minus stations would be used, as − 1 + 45.

Side. Trial centerline stakes may be set either from plans or by eye. When the location is approved, side stakes are usually set to aid in the estimating and construction. These may be shoulder, gutter, slope, and reference stakes, the locations of which are indicated in the figure.

Each stake should be marked to indicate its location, but when this is obvious, as is often the case on large jobs, it may be omitted. Centerline is indicated by the symbol ℄, or ¢, or ⁄c. On other stakes, the location or its abbreviation may be written.

A side stake's distance from the centerline may be indicated by the low figure on the back, or cut or fill side, or by a figure on the front, below the station if marked. The direction should be indicated by the letter R for right, or L for left. Such directions for plus stations are read looking from the zero stake.

In some localities 25-R would mean 25′ right of the centerline; in others that the centerline was 25′ right of the stake.

Side stakes are set on lines perpendicular or radial to the centerline.

Grades. Grade markings indicate the cut or fill required to bring the ground surface down to or up to the grade required by the plans. Center and shoulder stakes usually indicate vertical cut or fill; slope stakes in-

dicate vertical distance to road level. Cut is indicated by the letter C, fill by F.

If a slope stake indicates a cut of four feet, and the slope is one on two, the desired shape is a straight line from the base of the stake to a point eight feet nearer the road center, and four feet below the stake.

The slope stake should also indicate the distance to the center of the road. If the road and gutter width is known, the slope can be calculated from the stake's depth and distance figures.

Cuts and fills may be figured from the base of the stake (ground level), from its top, or a line drawn on it. Any basis except ground level is confusing to operators and may cause serious mistakes. However, ground level should be marked in case soil falls away or is added without disturbing the stake.

If the fill is less than the height of the stake, the grade may be marked directly on it with crayon. It is an excellent practice to tie a rag around the mark to make it readily visible to the operator.

Shallow cuts may be marked temporarily with rags a specified distance, as one or two feet, above grade, so that operators will not have to dismount to read the figures. These should be a different color to avoid confusion with the fills.

A great number of rags can be made of one old sheet by tearing it in narrow strips. If none is available, unsterilized one-inch bandage can be bought quite cheaply for the purpose. These cloths are easily dyed.

When the grade is near finish, stakes are driven at shoulder lines, and at as many intermediate points as are desired, so that their tops are at grade. These tops are colored with crayon, usually blue, and the stakes are known as blue tops. It is a good plan to mark any which are buried with a light marking stake which can be bladed off when it becomes unnecessary.

Operators should exercise great care when working around stakes as they are valuable, both as guides to correct work and in relation to replacement cost. In general, an occasional stake can be replaced readily, sometimes without instruments, but a group of them may involve considerable work for surveyors.

Errors. A new set of stakes may not agree in grade or location with the missing ones. This difficulty might arise from an error in the original settings or in replacing them. A satisfactory road can often be built according to an error, but seldom when right and wrong markings are mixed together.

Stakes are accepted as correct until discrepancies are noted. If any stake appears to be out of line, or badly off grade, it may have been moved or disturbed; it may be a base line or other marker, or a mistake may have been made in placing or marking it.

When possible, the surveying crew should be recalled to check it. If this is not practical, the foreman may be called upon to use his own judgment about whether it should be re-measured. It should not be disturbed, however, unless absolutely necessary, as the suspected stake may be right and others wrong.

Reference. All stakes standing on areas to be cut will be dug away, and those inside fill lines will be buried. In shallow cuts, stakes can be left temporarily in islands; and in shallow fills long stakes may be used which will project from the top, unless they are knocked over. Slope stakes are liable to be undercut or buried. Any stakes are apt to be moved by accidents, particularly if the ground is stony or frozen.

It is therefore desirable to set reference stakes well outside the work lines to simplify resetting of the work stakes. Placing of these is described in Chapter 2.

Surveyors usually have a base line which is partly or wholly outside of the roadway. The points in this may be more important than any stake in the road itself. Machinery

should not be allowed to wander around outside of the work area, except in places where there is assurance that there are no stakes, or where they are prominently marked or heavily guarded.

FILLS

Fills are made to bring a road or area up to a desired grade, to elevate it above water or drifting snow, to bury stumps or rocks, or to add strength to ground too unstable to support road surface or traffic.

Fill may be obtained by the removal of high spots or banks along the same road or project, by digging gutters or ditches alongside or near the fill, or by hauling from necessary excavation on other jobs, from commercial pits, or borrow pits opened just to obtain the fill.

Nearby cuts on the same project are usually the cheapest source, as the digging costs and part of the hauling can be charged against the excavation. Also, excavation in adjacent hills will lower the grade, and thereby decrease the volume of fill needed to carry the road across hollows.

Roads in hilly country are often engineered to balance the cuts and fills, so that all the material cut out of high spots is just enough to build up all the low spots. However, where the road crosses ridges of hard rock close to the surface, good borrow is available nearer fills, or snow removal problems are severe, it may be advisable to keep cuts to a minimum and haul in dirt.

Where very heavy hill cuts must be made without a corresponding need for fill, the surplus may be wasted in dumps off the road. This may be preferred to raising road levels to absorb the fill, because of the economy of a waste dump as compared with a compacted highway fill. Also, high fills may require purchase of extra road width to avoid steep and dangerous side slopes.

Cuts and fills on a road are sometimes so far apart that combining them would cost more than wasting spoil from the cut nearby, and getting the fill from borrow pits.

Types of Fill. Any type of mineral earth or rock can be used as road fill, but clay and silt are generally undesirable. They soften when wet, frequently with changes in volume, and may act as a wick to bring ground water to the surface. Humus is avoided, particularly in its pure state, because of lack of bearing strength and excessive water absorption. Topsoil, a mixture of mineral soil and humus, may or may not be permissible, depending on its qualities and its location in the fill.

Sand and loose, clean gravel have excellent bearing power but afford poor traction, are hard to compact, and must be held in by other materials.

The most desirable fills are mixtures of two or more simple types. Varying proportions of clay, silt, sand, gravel, and stones are found in loams, boulder clay, and glacial till. Sand and gravel are most desirable when mixed with enough clay or silt to bind them together. Various soil mixtures are described in Chapter 3.

Light soils with a high percentage of sand or gravel are desirable when work must be done in rainy places or seasons. They absorb and drain off large quantities of water, and do not get slippery easily.

Moisture Content. The water content of soils largely determines their behavior on a fill. Each soil has a best (optimum) water content which favors compaction. Less water will allow the grains too free motion in relation to each other, and more will permit soil to bend or creep away from pressure.

A soil which contains too much moisture will develop a rubbery quality. It will move away from the roller, and when its weight has passed, spring back into nearly its original position.

A loose soil may hold too much moisture for best compaction and still appear fairly

dry. When the grains are squeezed together, water films between them are displaced and tend to work up toward the surface, rendering it wet. This condition may be cumulative through a number of layers of fill.

Some compaction is accomplished by rolling a rubbery soil, and the operation warms the ground and brings moisture to the top so that drying is speeded up.

If soil in the pit is too wet for the degree of compaction specified, it may be put through a drying kiln before being used.

If the soil is too dry, it is watered by sprinkling wagons while being spread and rolled.

Swell and Compaction. Undisturbed soil has generally been in the same position for long periods. The particles are well settled against each other, leaving little space. Natural cements may bind them together.

When such a soil is dug or disturbed, it breaks up into chunks or grains which are thrown against each other in a disorderly arrangement, leaving air spaces or voids between. This increases the bulk of the soil, and increases its ability to absorb and conduct water. Such a loosened soil will turn to a very soft mud if soaked.

The process of soaking and then drying will settle the grains together somewhat, reducing the voids. Repeated wetting and drying will cause it to shrink to about its original bulk. Freezing and thawing will accelerate this settlement, as will also the weight of traffic or additional fill.

Compaction by Hauling Units. Considerable packing down of fill can be done by hauling and grading equipment. Ground pressure under loaded scraper tires may be thirty to forty pounds per square inch, and the kneading effect of these tires and the vibration of crawler tracks are quite effective.

However, compaction tends to decrease with distance from the cut, as all the fill material must pass over the near portion, and only a small fraction over the far end. In addition, it is difficult, sometimes impossible, to get the operators to vary their routes enough to give systematic rolling to the full width. Routes may have to be shifted by stationing one or more men along the way to tell or signal the operators where to go, or by the use of movable obstacles.

It is usually inadvisable to have a heavily loaded unit break a new path in soft fill, as the power requirement and strain on the machine are excessive. Trail breaking should be done on the empty return trip, and loaded units then turned into those tracks.

Excessive rutting may be avoided by having a whole strip rolled by empties before using it for loads.

If enough units are hauling to make collisions likely, the two directions of traffic should be separated, and their routes alternated as necessary. If two-way traffic can use the same route safely, it can be gradually shifted to the side.

If a road fill is dumped loosely and not rolled, it may settle unevenly over a period of from six months to two years. Any surface placed on it during this period will be warped or broken.

It is generally not convenient, and often not possible, to allow a long period for subgrade settlement. Also, it is very difficult to estimate the compaction a fill receives from traffic, or from rains, while building. This makes it impractical to finish grade with a loose fill and obtain the desired surface after settlement.

These difficulties can be avoided by compacting the fill as it is placed. Rollers of various types are used on thin layers of fill to squeeze the grains into even closer contact than they had in the bank. They are aided by the weight of grading and hauling units. Loam soils may be reduced to ninety percent of their bank volume by thorough compaction.

A properly compacted fill should not shrink on exposure to time and weather,

so that it is theoretically possible to put a permanent surface on it immediately. In addition, it has the highest bearing power possible to its particular soil type, so that wheels and tracks will not sink into it much, and speed and capacity of hauling equipment on it is increased.

A compacted fill will not absorb rain water readily, so that the fill should remain hard enough to work even after heavy rains. Whether the surface will become greasy depends on the clay content and the possible presence of a layer of dry uncompacted dust before the rain.

Rollers. There are three principal types of rollers—smooth steel wheel, tamping or sheepsfoot, and pneumatic tired.

The smooth steel wheel models are just known as rollers. They are usually self-powered. Weights range from one and a half to over twenty tons.

These are primarily finishing machines, and are more often used on surfaces than subgrades. They have a high compacting effect at the top, but this diminishes rapidly with depth below the roll. Each layer compacted may have a tight top and a less well packed bottom.

These machines have little traction, and have difficulty on rough ground or steep grades. Special grid and segmented roll surfaces improve performance on fills.

Tamping rollers are steel drums four to five feet long, and 40″ to 60″ in diameter, which are fitted with legs or lugs that project about seven or more inches. Standard practice is to use three lugs to every two square feet of drum surface.

Legs may consist of shanks with expanded feet, or lugs of round or rectangular cross section, tapering from a wide base toward the end.

With either construction, the feet will penetrate soft fill so that a large part of the weight will be carried on the sole, and compaction will begin beneath it. As the ground is compressed, the feet will not sink into it as far and the roller "walks out" of the ground.

The drums can be filled with sand or water ballast. Sole pressures range from 250 to 750 pounds per square inch.

These rollers are towed by means of drawbars and box frames. Up to three may be mounted side by side, and two pairs may follow each other. Working speed is about 2.5 miles an hour, and power requirements in soft fills are heavy.

Pneumatic tired rollers are ballast boxes supported by wheels with smooth tread tires. The wheels may roll straight, vibrate, or move up and down or wobble as they revolve. They compact by a combination of weight and kneading action of the soft tire walls. Weights vary up to more than 80 tons. They can compact single fill layers as deep as 24 inches.

Fill Bases. It is desirable that a fill be firmly bonded to the surface on which it rests to prevent formation of saturated zones, water channels, and possible sliding downslopes. This is usually accomplished by removing vegetation and topsoil, and plowing ridges across any slopes.

Methods of removing humus and other muds from the location to be filled, and of stabilizing such muds when removal is impractical, have been discussed in Chapter 3.

When the area to be filled is wet, rough, or otherwise impassable to machinery, the first layer is built by dump trucks and dozers to a height at least sufficient to carry the hauling units over the soft spots or obstacles. After a usable floor is established, additional layers may be added by use of trucks, scrapers, or any other hauling equipment.

If the surface is uneven but passable, low spots may be built up first with compacted layers, or high spots removed, before the main fill is placed.

Rock Separation. Handling and compaction of fill material is rendered difficult by the presence of loose stone.

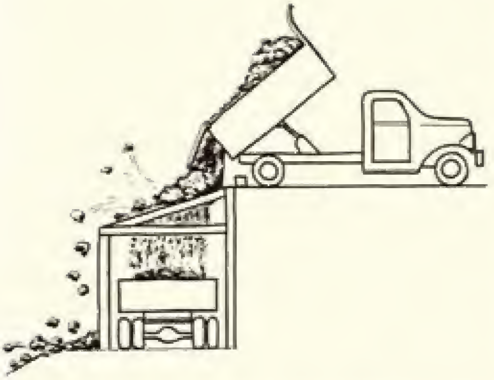


Fig. 8-23. Screening oversize rock from fill

Rocks of even small sizes interfere with grading. If their diameter is greater than that of the fill layer, they will project from the top. If two or more rocks are in contact, they are liable to prevent even distribution and compaction of fill under their adjoining edges.

For this reason, the size and number of rocks present in thin or layered fills are often limited. This may be done by using selected borrow, or by putting bouldery material through a grizzly.

The arrangement shown in Figure 8-23 represents a minimum of equipment for screening. A truck on a high level dumps on a sloping grizzly, dirt falls between the bars into a truck parked below, boulders roll to the side.

Oversize material may be allowed to roll directly into trucks, be loaded from beside the grizzly, dozed away from it to a stockpile, or, if the grizzly can be located on the edge of an abandoned pit, allowed to accumulate.

One or two men are needed to free oversize stones stuck between the bars and to coordinate the trucks. If the stones are a substantial part of the bulk of the soil, smaller trucks may be used under the grizzly than on top of it.

If sticking of stones or sliding off of chunks of earth is much of a problem, a vibrating grizzly, or a standard grizzly with a vibrator bolted to it, may be desirable. The flat slope illustrated is suitable only for loose soil and large openings.

Rock Fill. Various results are obtained from all-rock fills. If the largest pieces are smaller than the depth of the fill, and sizes are mixed, including a good proportion of fines, a solid fill with a good surface may be obtained by pushing piles off an edge with a bulldozer. Large pieces tend to move ahead and over the bank, while smaller ones drift under the blade to form a topping.

If there are not enough small pieces to provide a working surface, finer material should be brought to fill surface holes and even off the top.

Rocks too large to fit in the fill can be rolled ahead of it until a hole is found or is made to bury them, or they are reduced by splitting or blasting.

Rock fills are generally almost incompressible, exceptions being when rock is soft or fissured, and very heavy weights are used. However, they are apt to be subject to only minor and local settlement, where fines are shaken or washed into spaces between rocks below them.

Rock is desirable fill material for the bottom layer in crossing water or mud, as it is not softened by contact with water and spreads surface loads over large areas of the base. In such locations it may settle due to displacement or compression of the ground under it.

The volume of fill is greater than the unbroken rock in the bank. The difference will vary with the quality of rock, type of fragmentation, and amount and kind of compaction. 50 per cent is a rule of thumb average that can be used except where there are indications to the contrary.

If the rock must be used in the fill, it is best placed at the bottom. Unfortunately, rock is ordinarily the last material to be taken from a cut as soil is stripped prior to blasting.

SCRAPER FILLS

The standard method of building a fill with scrapers is to start with an area sufficiently leveled to allow the scrapers to travel on it, and to build it up in thin layers, starting at the outside edges, or at low spots.

Spreading depth may vary from two inches to the maximum lift of the bowl—eight inches to a foot. Thin layers favor compaction, particularly if the scrapers are depended on for the rolling and facilitate smooth building up of the grade. Chunky, sticky, or rocky fill will not spread thin, or can be made to do so only by very slow travel during the dump.

Thick spreading is liable to flow out of the bowl more smoothly; can be done at higher speed, and reduces the dump time. However, it tends to make a rough fill which will require slower travel speeds, or smoothing work with a dozer or grader.

Edges. If a fill is high, the edges may be troublesome and dangerous unless carefully made. The problems involved are keeping it at the correct toe alignment, proper slope, at full density or compaction, and not rolling any machinery off it.

These problems are affected by the nature of the fill and by its height and slope.

Loose fills of sand, clean gravel, or too-dry dirt tend to cave under the weight of machinery close to the edges. Finer grained fills may have excellent bearing power if well compacted and not too wet. However, while being compacted, they tend to squeeze outward, and an allowance for this creeping must be made when placing the first fill so that it will not move out past the toe stakes.

The behavior of the fill on edges may be anticipated by making soil analysis or by consulting with contractors or machinery operators who have worked with the same formation.

Except for allowance made for creeping under load, or spillage from above, which seldom should be more than a foot or two, the fill is started at the toe line and built up of layers, usually not over six or eight inches, loose. Each layer should be rolled with a tamping roller that is allowed to project slightly beyond the edge. For this purpose, two or more rollers should be fastened in a single yoke so that their width will be substantially greater than that of the towing tractor, that should not have to walk on the edge. This is particularly important with high banks and wheel tractors.

If watering is required for proper compaction, application may be somewhat heavier at the edge to allow for side evaporation. However, it should not be sufficient to make it soft or muddy.

The fill should slope up at the edges in order to incline the center of gravity of the machinery toward the center and minimize the danger of caving. If the fill is narrow it will have a trough shape, and if wide, it will be flat with raised sides.

This slope is most easily started by a grader or an angle dozer working over the first layer or two left by the scrapers. Once made, it will tend to preserve itself as the tilt will tend to make the inside wheels of the scraper sink deeper. If it becomes too steep, it is readily reduced by filling toward the center.

If the job is shut down during any period when rain is expected, it may be wise to build the fill up to a crown in order to allow it to drain. This involves resloping the edges on resumption of work, and, if the work is done under exact compaction specifications, may cause confusion in the treatment of the tapered layers required.

Another treatment is to preserve the trough but so grade it that all water will flow to selected low spots. Here ditches are dug through the raised edges, and troughs of metal or wood placed to lead the water down the slope. This is readily done in hilly country where most of the road is on

definite gradients, but not in level country.

Such drain ditches may be made wide and gentle, so that they can be dug, backfilled, and compacted by machinery, or may be hand dug, refilled, and tamped.

If the trough shape is left without precautions, a center gully may be scoured by a heavy rain, a pond formed in low spots, and damage done to edges by overtopping and concentrated runoff.

Scraper distance from the edge is determined by depth of spread and slope. If a slope is one on two, spreads are six inches deep, and compaction is one third, each pass will be eight inches inside the previous one.

If the edge is not firm enough to support scrapers at the proper distance to dump loads, they should be spread farther back and the dirt cast out to the edge by a grader or angling dozer.

Additional slope stakes should be set as a high fill is built up to maintain the correct width.

DRAINAGE

Drainage is an important factor in the construction of most roads. Ground water must be kept far enough below the surface so as not to damage it, or weaken the subgrade directly or by supplying capillary water. Water falling on the surface of the road must be conducted off it, and run-off or streams crossing the road must be provided for.

Frost Heaving. Capillary action in silt soils is largely responsible for frost heaving of pavements. This may occur when the ground freezes below the pavement level to the top of a silty layer in contact with ground water. The water in the top forms an ice crust and capillary water feeding from below adds to it from the bottom. An ice lens of considerable thickness may form in this manner, pushing the pavement up as long as the temperature provides a balance between the heat liberated by the ris-

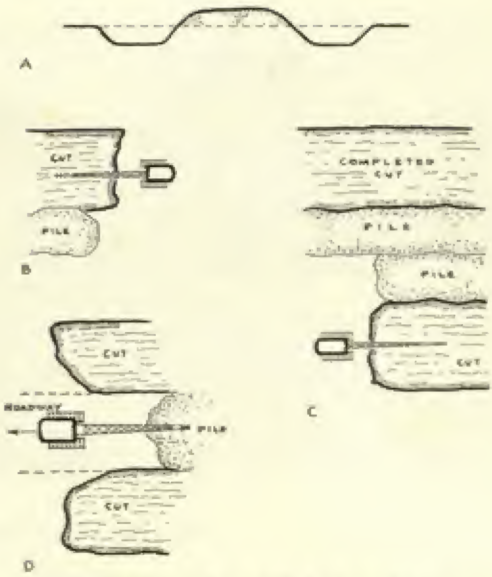


Fig. 8-24. Road fill from gutters

ing and freezing water, and the loss of heat through the pavement.

Deeper freezing may plug the circulation and stop the heaving, or cause formation of additional lenses at greater depths. Thawing will allow the lens to melt and liberate excessive water, and the broken pavement above it may collapse.

Capillary water can be controlled by using a coarse, pervious fill under the surface to a depth sufficient to provide necessary bearing power and to get below frost line; or by lowering ground water level and intercepting surface water which might enter the subgrade.

Raising the Grade. In swamps and lowlands, the only practical method of getting the road well above ground water is to build a high fill. If the base course can be made entirely of rock, it will break any contact between the water and the balance of the fill. Clean gravel or coarse sand may serve the same purpose.

Proper quality of fill can reduce the required height substantially. However, it is often more economical to make a higher fill of inferior material obtained from roadside ditches, as in Figure 8-24 (A), and it

Fig. 8-25. Borrowing road fill from sides

is often possible to lower the water level by the same operation. Draglines are generally used, but dipper dredges may be preferred when much of the land is under water, or it is intersected by numerous channels.

Either machine may work along the ditch lines, piling spoil toward the center, as in (B). The dragline will work away from the cut, as shown, but the dredge will float in it.

If a dragline has a sufficiently long boom, it can travel on the road centerline, and dig both ditches and pile the spoil in one pass, as in (D).

Road fill may also be obtained by ditching in dry flatlands where the road is to be raised above floods or snowdrifts. In such circumstances elevating graders may be used as shown in Figure 8-25, or dozers or scrapers.

Tiling. In sloping land, it is usually more economical to lower the water table by drainage. The standard method, Figure 8-26, is to put shallow ditches to carry surface water through cuts (A), and, if necessary, to place porous tile or other drains (B) two to three feet deeper in loam soils. Silt or clay deposits may require a drain depth of as much as seven feet, but in such a case better results may be obtained by a normal drain depth and by the use of a layer of pervious material under the road.

The design of subsurface drains must be carefully adapted to the requirements of the particular job. The ground may drain naturally so that no work is necessary. There may be a saturated condition that could be relieved by providing a drain through an impervious barrier (C), or by cutting off the source of water (D). There may be springs or seepage rising under the road which would require center or lateral drains (E) and (F). Such drains may also be required to take off water soaking through a porous road surface.

When the ground is generally dry and firm, but has local springs or seepage, the wet areas should be dug well below the intended drain, and backfilled with stones and clean gravel, topped with sand. The drain itself may be any type of pipe, laid at the lowest convenient level, and opening into side drains, a catchbasin, or a gutter.

The rock fill directs the water toward the pipe and reduces or eliminates softening of adjacent areas.

JOB STUDY

Road construction may involve clearing vegetation; stripping and storing of topsoil;

excavating soil and rock to cut natural levels to road grades; hauling the spoil to road fills or waste dumps, building culverts, bridges, and drainage systems; raising low areas to road grade by fill obtained from highway cuts or borrow pits, and finishing, topsoiling, and seeding of slopes; and cleaning up the work area.

Usually, this work must be accomplished within a time limit. It is desirable to get the maximum number of machines and men on the job as soon as possible after the start, but it is more important to keep them efficiently employed once they are there.

Sequences. When time permits, it is often desirable to perform complete operations in sequence. If an entire work area is cleared, it will usually be easier to arrange dirt moving sequences than if the excavators have to be limited to a few small sections. Culvert construction should be completed before fills are raised high enough to go over them, unless they are to be installed by ditching the completed subgrade.

Liberal areas of rock should be cleaned before drilling starts. Pioneer bulldozer work should be well advanced before scrapers operate.

If the schedule is close, delay in one operation will delay others that have to wait for it, which may be more costly in machine and man time. These secondary delays are much more serious when maximum amount of equipment is crammed into a job than when a few units are doing it over a longer period.

Basic Factors. Basic factors to be considered in figuring grading for a road may include:

1. Clearing costs.
2. Topsoil stripping, storage, reclamation, spreading, and planting.
3. Amount and type of soil excavation in cuts or borrow pits.
4. Amount and type of rock excavation.

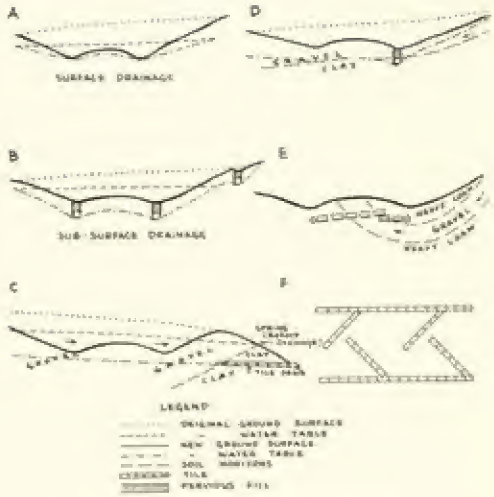


Fig. 8-26. Road subdrainage

5. Availability of suitable borrow and cost of purchase.
6. Haul road construction and maintenance, and length of hauls.
7. Quality of fill required, and processing required of material from cuts and pits.
8. Fill compaction, shrinkage, and disposal of surplus.
9. Slope finishing and protection.
10. Ground water conditions and drainage requirements.
11. Structures such as bridges, culverts, and retaining walls.
12. Possession or availability of proper machinery, with necessary parts and supplies. Extra costs of using second-choice or beat-up equipment.
13. Availability of construction supplies such as pipe, forms, etc.
14. Labor supply.
15. Weather—rain, snow, ice, dust, frozen ground, frozen equipment, mud.
16. Time of completion of related structures such as bridges, being built under separate contract.

In highway work, the amount, kind, and location of cut, borrow, and fill, and the length of haul, may be specified. Haul may be described as "normal" or free, up to

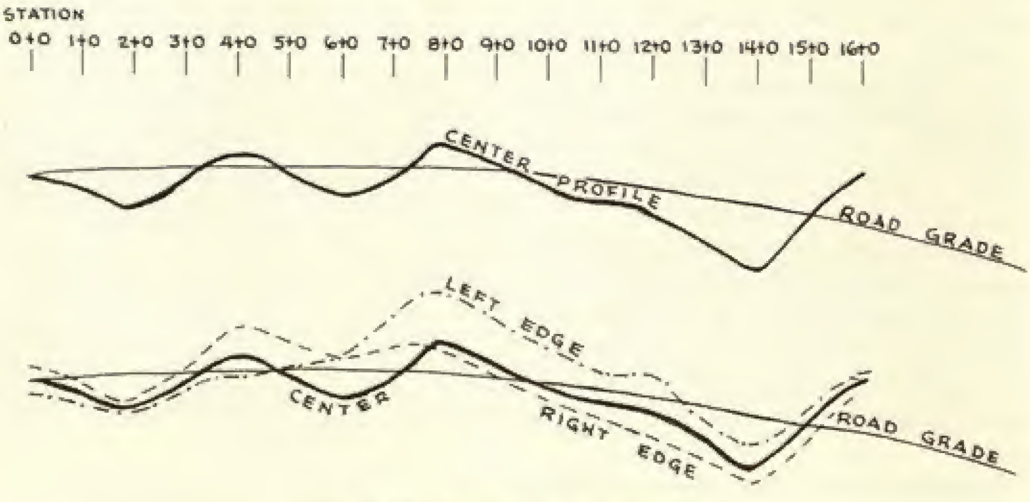


Fig. 8-27. Center and side profiles

a certain distance, which may be 300 to 1000 feet, and longer hauls called "overhaul." Excavation may be described as "unclassified," or divided into rock yards and dirt yards.

In less formal jobs, these factors may be indicated only approximately, or may be figured by the contractor from grade or route plans.

Casual Estimating. Where cuts and fills are shallow, and side slopes lacking or moderate, grading can often be estimated fairly accurately by inspection of centerline stakes. The exact yardage is sometimes not of primary importance, as stripping topsoil and working over a piece of ground represents an amount of machine time that may be only moderately increased by the cuts and fills.

Several errors must be watched for, however. Cuts and fills on the stakes may be figured from the top of the stake, from ground level, or from a line on the stake. The grade indicated may be subgrade, in which case it is taken at face value, or finish grade when the depth of base courses and of surfacing must be added to the cuts and subtracted from the fills. The width to be figured on is not only the road and shoulders, but also gutters and slopes. The depth of topsoil to be stripped is subtracted from the cuts, added to the fills, and is considered separately as an important cost factor.

When cuts or fills are deep, side slopes exist, topsoil need not be stripped, or when the job is large, yardages should be carefully calculated. If this is not done on the plans, the contractor can do it for himself.

YARDAGE CALCULATION

Center Profile. The minimum staking for a road is the centerline. When this is done, a profile is taken, showing the elevation of the ground at each stake. These elevations are plotted on cross section paper, usually with the vertical scale ten times the horizontal, and the points connected by a line. A profile for the road is then sketched in according to the standards of grade and vertical curve required, or from some previously formed plan. This line should represent the subgrade before the addition of any imported material.

Distances measured from the road line to the ground line will indicate the depths of cut and fill required to establish the road grade. If topsoil is to be stripped, its

depth should be added to the fills and subtracted from the cuts.

If the ground does not slope across the line of the road, this type of profile, shown in Figure 8-27 (A), should give a reasonably accurate picture of the relative volume of cuts and fills, and the distances they are to be moved. However, to obtain yardages, cross sections usually must be calculated, as described below.

Side Profiles. If the road is laid out on side hills, side stakes and slope stakes may be set. The side stakes may be at the edge of the pavement, at the outer edge of the shoulder, or the far side of the gutter, if any. In general, the shoulder or the gutter locations are preferable. Slope stakes are placed where the intended cut in a bank reaches its top, or at the outer, base edge of a proposed fill. These are not placed until cross sections are calculated.

If the side stake elevations are plotted in the same manner as the centerline, two additional profiles can be drawn, as in (B). These will give additional information about the bulk of material to be moved, but since they often do not include cuts for gutters, and cannot show the volume which must be dug or filled for side slopes outside the road lines, they are not an adequate basis for careful calculation.

Cross Sections. A cross section is a profile taken at right angles to the line of the road. It is at least long enough to include the full width that will be graded. Such profiles are sometimes taken with hand or string levels. They may be taken at each 100′ station, plus points where the ground surface changes, or, in smooth terrain, less frequently.

This cross profile is also drawn on cross section paper, preferably on the same vertical scale as the center profile. Horizontal scale may be the same as vertical, or at any convenient proportion to it. The cross section of the road subgrade is drawn in.

A number of such cross sections are

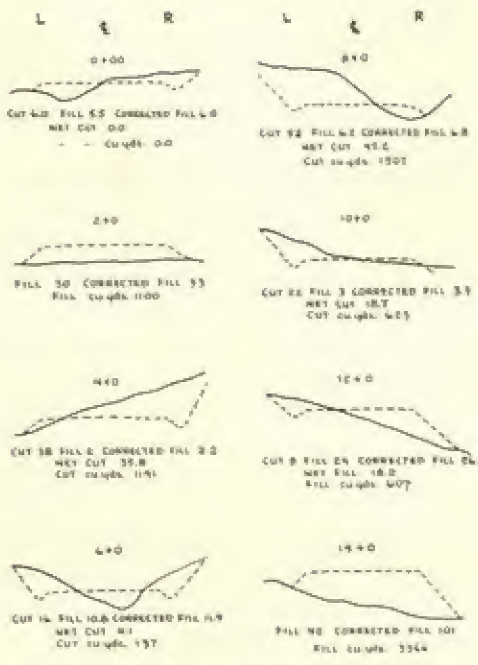


Fig. 8-28. Cross sections

shown in Figure 8-28, together with the cut and fill for each.

Wherever the ground line is above the road line, there will be a cut; and where the road line is higher than the ground line, there will be a fill. If topsoil is to be stripped and saved, it may be well to lower the ground line by the depth of the topsoil to save confusion.

The most convenient way to measure the areas of cut and fill is by counting squares and fractions of squares. If a lot of work is to be done, areas can be measured by means of a planimeter.

Fill Shrinkage. When fills are rolled to the compaction required in modern highways, the material is often compressed into a smaller space than it occupied in the bank. This shrinkage should be allowed for in figuring cross sections. Loam soils often shrink 10 percent, clean sand 5 percent or less, and blasted rock, not mixed with other dirt, will show a minus shrinkage, or swell.

Compaction by hauling equipment with-

out rolling is variable and will seldom cause shrinkage.

The examples in Figure 8-28 use a shrinkage factor of 10 percent, but the figure selected should depend on job conditions.

Net Cut or Fill. On side hills, one station is likely to include both cut and fill. The smaller amount is subtracted from the larger, giving net cut or net corrected fill.

Converting to Cubic Yards. The net square yards of the cross section are converted into cubic yards by multiplying by the length of the road it represents. If sections are taken at 100 foot intervals, each will represent a piece 100 feet long, that is, halfway to the next section, on each side. If a special section is taken 40 feet from a 100 foot station, it will cover 20 feet on one side and 30 on the other—a total of 50 feet. The adjoining sections will be reduced proportionately.

When the 100 foot interval is used, it represents 33⅓ yards. It is easier to multiply the section square yards by 100, then divide by 3, than to multiply by 33⅓.

The net cut and net fill figures, when converted to cubic yards, are used in making a mass profile. The gross cut figures are converted to cubic yards, in the same manner, to determine the total excavation, exclusive of topsoil.

Topsoil volume is figured by multiplying the length of the road, the average width to be stripped as indicated by the cross sections, and the average depth.

Cubic yards of net cut are added together and compared with the total of net fill yards, to determine whether extra fill will have to be obtained from pits; or whether fill will have to be wasted outside the road area.

Mass Profile. A mass profile is prepared by drawing on cross section paper a straight line to indicate the road grade, dividing it into stations, and posting cubic yards of net cut above it and net corrected fill below it, on any convenient scale. It is sometimes helpful to draw in blocks representing the fill at each station as in Figure 8-29.

A curved line, the mass profile, is drawn connecting the station points. The amount of net cut or net fill at any point along the road can now be scaled off, as well as the haul distance between cuts and fills.

The haul distance is measured between the centers of mass, or centers of gravity, of the cut and fill. The longer and shorter hauls should average out.

Mass Diagram. Many engineers prefer to use the mass diagram shown in (B). A straight base or zero line is drawn on cross section paper, and marked off for road stations, and plus and minus yardages in the same manner as for the mass profile.

Points are plotted for cumulative or total yardages, starting at zero station. Points are placed half an interval farther to the right than the station they represent, as the full yardage figured for each station is not accumulated until the end of that station block.

At station 1 + 50, the minus yards of fill for station 1 + 0 is entered. At station 2 + 50, the total of the fill for stations 1 + 0 and 2 + 0 is posted, and at 3 + 50, the total fills for stations 1, 2 and 3.

When a cut is reached, at 4 + 0, the cut yardage is subtracted from the accumulated fill so that the line turns up. This line, called the mass curve, crosses the baseline when accumulated cut equals the accumulated fill, and continued cuts raise it above that line, until a fill is reached and pulls it down.

In short, wherever accumulated fill, starting at zero station, exceeds accumulated cut, the mass curve will be below the base. If there is an excess of cut, it will be above.

The mass curve line does not show total yardages of either cut or fill.

The points of loops which are farthest from the base line indicate changes from cut to fill, or fill to cut. They also represent

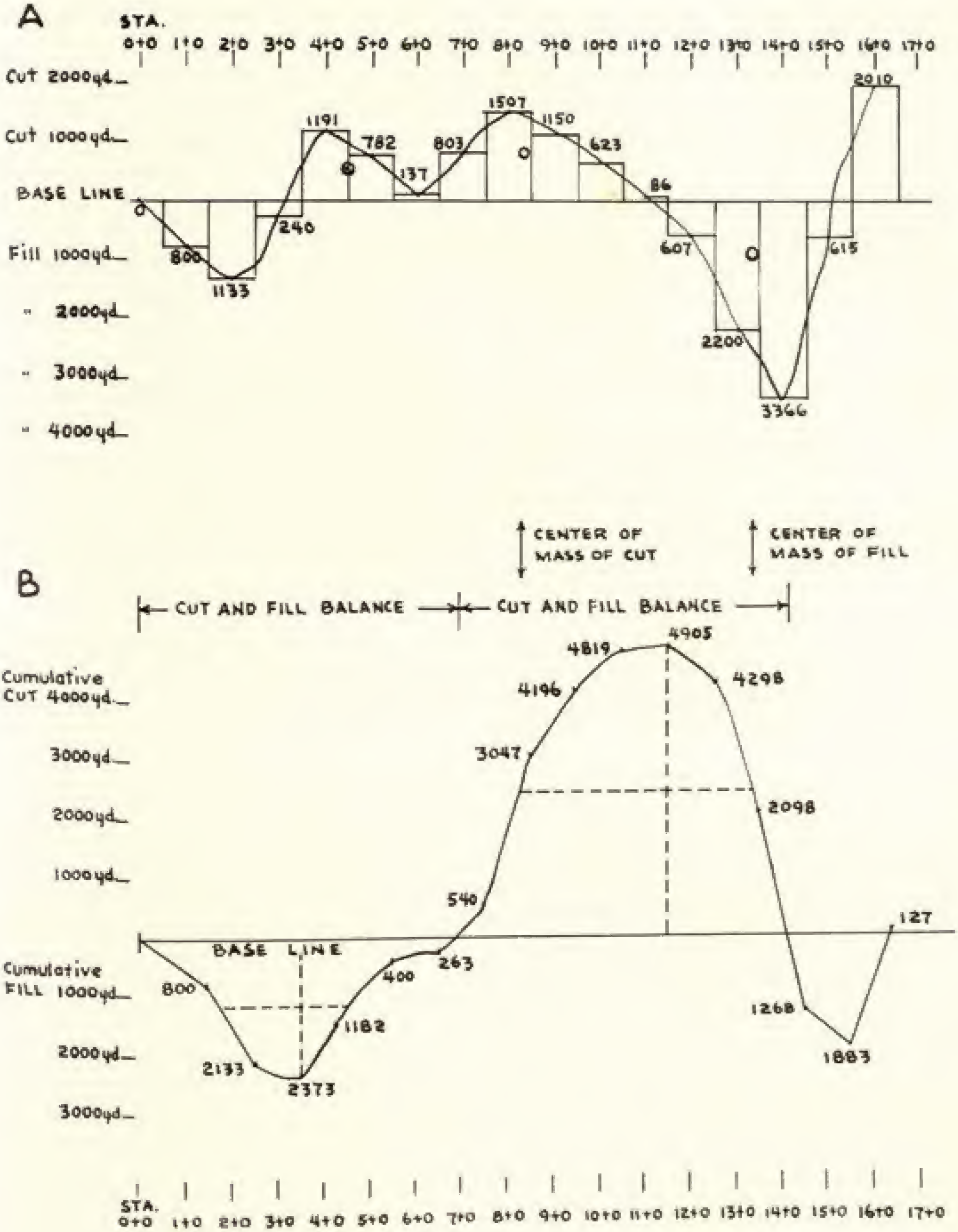


Fig. 8-29. Mass profile and mass diagram

the total net yardage to be moved from cut to fill along the road line, but disregard sidecast material.

Any horizontal line drawn on the diagram is called a balance line. The yardage between any two places at which it intersects the curve have a balance of cut and fill. The baseline will often serve as a balance line, as in the illustration.

The centers of mass of a cut or fill can

be found by drawing a vertical line from the outermost point of a loop to the balance line. A horizontal line is drawn through the center point of this vertical. Its points of intersection with the sides of the loop are approximately at the center of gravity of the cut and the fill for that balance line.

A single balance line may be used for the whole road. Any part of the mass curve which extends beyond the last balance point to the first or last station of the road, will represent yardage to be borrowed, if it is below the base; or to be wasted, if it is above.

A loop above the balance line indicates fill movement to the right in the diagram, and below it to the left.

Any number of balance lines can be used so long as they end in points on the mass curve, and do not overlap. The vertical distance between two balance lines represents borrow or waste in the part of the curve connecting them.

The mass diagram is a very flexible and useful aid in studying yardage distribution. However, it is so confusing to persons not accustomed to this type of computation that the average contractor working out such a problem may do better to use a mass profile.

CHAPTER NINE

BLASTING AND TUNNELING

For the purposes of this chapter, rock is defined as any material which requires loosening by explosives in order to be dug economically by available machinery.

PURPOSES OF ROCK EXCAVATION

Surface excavation of rock is done chiefly for the following purposes:

1. Stripping—the removal and wasting of any type of rock or dirt in order to uncover valuable layers.

2. Cutting—removal primarily to lower the surface. In road and airport construction the spoil is generally used for fill elsewhere on the project. In ditching, it is often used for backfill after installation of pipes.

3. Quarrying or mining—excavation of rock which has value in itself, either before or after processing. A rough distinction can be made between these two in that quarries are ordinarily concerned with the physical characteristics of the stone, and mines with its chemical composition. However, the terms will be used interchangeably in this discussion.

One excavation can involve all three classifications, as in a heavy road cut where some material is wasted, some is used for road fill, and the best rock is crushed and used for aggregate.

Blasting may be divided into a primary operation in which rock is loosened from its original position in bulk, and secondary work which consists of reducing oversize fragments, and breaking back ridges and spurs. The latter is done in the same manner as other light blasting, such as breaking boulders and chipping out ledges.

Rock work may also be classified as to the type and fineness of breakage required. Quarrying of building or dimension stone involves loosening large solid pieces from the parent rock, while blasting for fill or crushed rock requires pieces small enough to fit in the shovel bucket, the fill layer, or the crusher.

Stripping. In most stripping work, the spoil has no value so that the cheapest way of handling it is the best way. It is usually possible to dump it in excavated areas from which the pay material has been removed.

It is common practice to shoot and dig overburdens up to a hundred feet deep in a single layer, and the use of the largest shovels and draglines is required for such work.

Drilling may be done horizontally from a face, as in Figure 9-1 (A), vertically from the top, as in (B), or in combination, as in (C).

Horizontal drilling has its best use when the mineral deposit is immediately under soft rock. Auger type drills with extensions six to ten feet long, and diameters of about five inches, are used. These have a tendency to drift downward, and since distances of thirty to seventy-five feet are

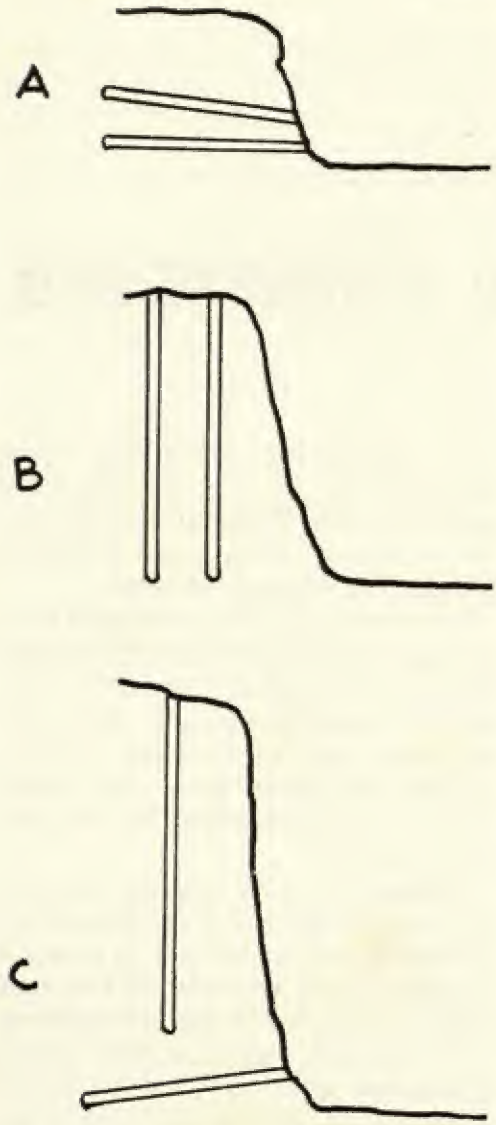


Fig. 9-1. Horizontal and vertical drill holes

commonly drilled, it is necessary to start them several feet above the deposit, or to start them at a slight upward slant. Spacing may be ten to thirty feet.

If the mineral is coal, it is important that charges be sufficiently high above it, or light enough so that it will not be crushed by the blast.

If there is any considerable amount of hard rock such as limestone or sandstone in the overburden, vertical drilling is required. Churn type drills with bits from four to twelve inches are generally used. Burdens from 25 to 50 feet and spacings from 25 to 35 feet are common. Holes are stopped a few feet short of contacting the coal to avoid shattering it with the blast.

Scrapers are sometimes used to remove most of the loose soil before drilling. This saves a considerable drilling footage, makes casings unnecessary, and, on low and medium faces, makes possible the use of wagon drills.

If the pit area is to be regarded when work is completed, the scrapers can be used to fill the hollows between the piles left by the shovels, or to place topsoil over regraded areas.

Because of the tremendous size and power of the excavators used in large pits, the blasting need only shake up, crack, and loosen the overburden without producing fragmentation comparable to that required in a cut or quarry. Wide spaced holes and light charges can therefore be used successfully.

Highway Cuts. Rock cuts for highways may be of the through type, Figure 9-2 (A), and the sidehill (B). Material from a sidehill cut may be thrown down to make a fill, as in (C).

The area to be cut should first be cleared and stripped of loose soil, and preferably of rotten rock. This may be done with dozers, scrapers, or shovels, depending on the conditions and the equipment available.

If the rock is soft, its upper surface may be loosened with rippers and removed, along with any dirt pockets it may contain. If it is hard and irregular, extensive cleaning by hand and with small equipment may be necessary. It is desirable to remove all loose dirt, particularly if the rock is to be used as crusher aggregate for road topping.

When water and disposal areas are available, hydraulic cleaning with contractors'

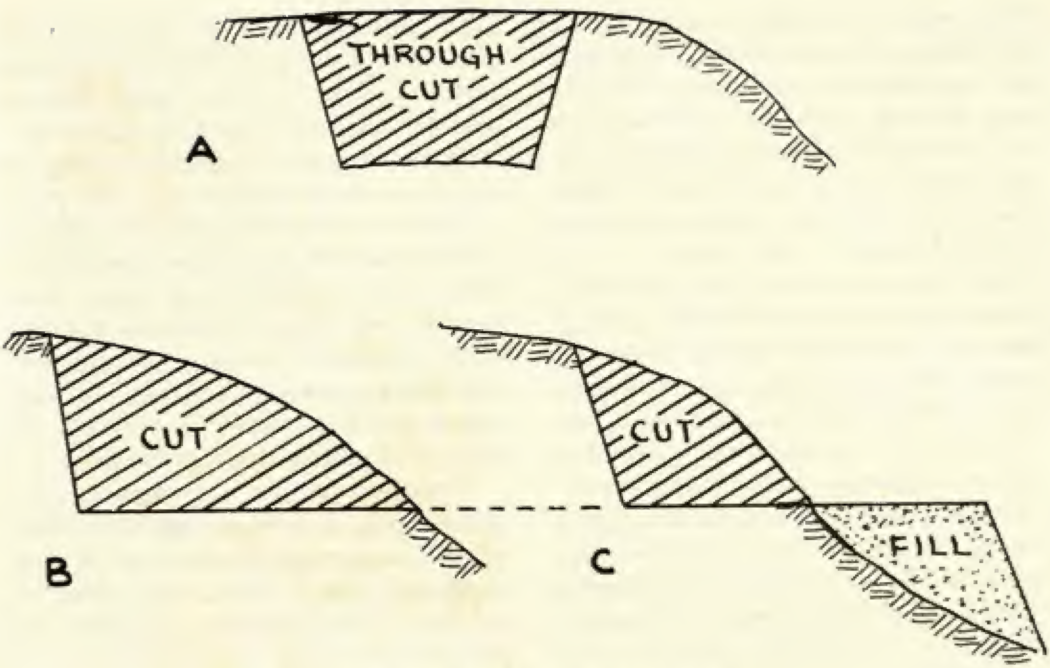


Fig. 9-2. Through and sidehill cuts

pumps and fire hose or with special equipment may be used.

If cleaning is not practical over the whole area, the spots to be drilled can be cleaned individually. The top layer may then be drilled, shot, and removed for fill, and any clean rock required can be obtained from lower levels.

If the cut is twenty feet or less in depth it may be taken in a single layer, but depths of 12 to 15 feet are generally considered most satisfactory for wagon drilling and removal by one to two and a half yard shovels.

In a through cut, the full width is used as a face to provide maximum space for machinery. On a sidehill, the same technique or one or more bench faces parallel with the centerline may be used.

Degree of fragmentation required is determined largely by the depth of fill layers where the spoil is used.

Mining and Quarrying. Pit operations are largely conducted to obtain certain classes of rock or earth. The general aspects of this work will be discussed in the next chapter.

Rock excavation may follow highway techniques in exploiting comparatively narrow or irregular veins; or large scale stripping work may be necessary to make pay rock accessible.

Pits are often distinguished by the use of high and wide faces; or holes sunk below surrounding grades, with access by ramps or inclined or vertical hoists.

It is advantageous to have the face wide enough so that several operations can be carried on in different sections with minimum interference.

The fineness of fragmentation which must be obtained by blasting is generally determined by the size of the hoppers or grizzlies on the crushers or processing machines.

EXPLOSIVES

General Properties. Commercial and military explosives are chemical compounds or mixtures, which can be decomposed

quickly and violently. They may break up by a process of rapid burning (deflagration), or almost instantaneously (detonation). In either case, the original solid or liquid chemicals are largely changed into gases, which have a much greater volume. Heat is generated by the change, and serves to expand the gases still further.

There are a number of properties of explosives to be considered when selecting them for a job. These include sensitivity, strength, density, velocity, water resistance, fumes, perishability, price, and availability.

Sensitivity is a measure of the ease with which a substance can be caused to explode and its capacity to maintain explosion through the length of the borehole. This factor is also important in determining whether a particular explosive can be safely used.

Most commercial explosives are in an intermediate classification, being less sensitive than some of the compounds (such as nitroglycerin) from which they are made, but being less stable than military explosives.

Strength is the energy content of an explosive in relation to its weight. Density is the volume of the explosive in proportion to its weight. Both these properties are chiefly used in classifying dynamite.

Velocity is a measure expressed in feet per second of the speed at which the burning or the detonation wave travels through an explosive. It varies from 1,000 to 3,000 feet per second for black powders to 23,000 feet per second for blasting gelatin.

Low velocity explosion has a heaving and separating effect, while high velocity crushes and shatters.

Water resistance is an important factor in wet rock, and varies not only with the character of the explosive, but the manner in which it is packed and wrapped. Manufacturers are increasingly able to put water resistance in the explosive rather than in the wrapper.

The gases resulting from explosions vary in toxic and irritating qualities. This is very important in underground work, particularly if ventilation is poor. Explosives are rated by the manufacturers according to fumes, as excellent, good, fair, and poor.

Explosives vary widely in the length of time they can be kept under various conditions before deterioration makes them dangerous or useless. Dynamite was formerly damaged by freezing, but this difficulty has been entirely overcome. Spoiling may be a serious factor if use is subject to delay, particularly in hot wet weather.

Different dynamites vary widely in price, and the most economical type for a certain use is often in the higher brackets. In other words, a dynamite should be selected on the basis of final results, rather than first cost.

In many areas, very few types of explosive may be available, and because of the complications of shipping, delivery of special orders may be delayed weeks or months. Under such conditions, use of the standard dynamite may be advisable even if it is not exactly suited to the job.

If special explosives are purchased from a contractor or a quarry, it may be necessary to handle the transaction through a dealer in explosives to comply with state laws.

Permissible dynamites are those approved by the U. S. Bureau of Mines for use in gassy and dusty coal mines. Their most important feature is minimum flame in the explosion.

Black Powder. The explosives which explode by burning, are called "low explosives." Black powder is the only commercially important member of this class, and is the oldest explosive known.

Black powder is ordinarily composed of sodium nitrate, sulfur, and charcoal, finely ground and combined in grains of various sizes. The grains are then coated with graphite or other glazing to make it free-

running. A more expensive powder for special purposes uses potassium nitrate instead of the sodium compound.

Fine grain powders burn and explode faster than coarse grains. Somewhat more powder can be packed in a borehole by mixing two or more grain sizes.

Black powder can also be obtained in pellets, which are short cylinders of compressed powder with a center hole. They are wrapped into eight inch cartridges resembling dynamite in appearance. They are more convenient to use in small boreholes than the loose powder, and are somewhat safer to handle.

Black powder may be ignited or exploded by flame, heat, sparks, or concussion, and requires more careful handling than most dynamites. A special hazard is that powder spilled on the ground or on the magazine floor may ignite if stepped on or scuffed.

The blasting action will depend on the degree of confinement, the bulk, the grain size, and the closeness of packing. Unconfined powder will flash burn, without explosion; and poorly confined powder will waste much of its energy along the path of least resistance.

Black powder produces considerable smoke, and quite toxic fumes the quantities of which vary considerably in different blasting procedures.

Black powder can be used to advantage when large, firm pieces of rock are desired, or when the material being blasted is soft and resilient enough to absorb the shattering blow of high explosives.

It cannot be used underground where ventilation is poor, or where the air may contain inflammable gas which may be ignited by the flame from the powder, or in wet holes. It is being replaced by dynamite in most applications.

Dynamite. Dynamite is now the best known and most widely used commercial high explosive. The term includes several different chemical groups, wrapped and marketed in about the same manner as each other. Only the most general distinctions may be made among them, as research is steadily widening their applications.

The "straight" dynamites consist primarily of a mixture of nitroglycerin, sodium nitrate, and combustible absorbents such as wood pulp, wrapped in strong paper to make a cylindrical cartridge. Although a wide variety of sizes is available, the most popular are eight inches long and one and one eighth or one and one quarter inches in diameter.

The percentage of nitroglycerin by weight contained in the mixture is used to identify it, according to strength. From 15 to 60 percent may be used.

Strength does not increase in proportion to the percentage of nitroglycerin because the other ingredients also contribute gas and heat. For example, a sixty percent dynamite is about one and a half times as strong as a twenty percent.

Higher percentages are faster and more sensitive. Speed is desirable in hard rock and where the explosive is not confined, as in mud capping boulders. Sensitivity is necessary when blasting mud ditches by the propagation method.

Straight dynamites have fair water resistance. Their fumes are poor, however, and they are never recommended for underground work.

Any type of dynamite of the general purpose 40% strength will explode if subjected to sharp concussion, such as explosion of a blasting cap; from impact of a rifle bullet; from excessive heat, whether produced by fire, friction or impact, and from sparks.

When dynamite is burned—usually to destroy surplus or deteriorated stock—it is spread in a thin layer on straw or other combustible material, which is ignited. All personnel should keep at a safe distance from the fire. Dynamite will usually burn

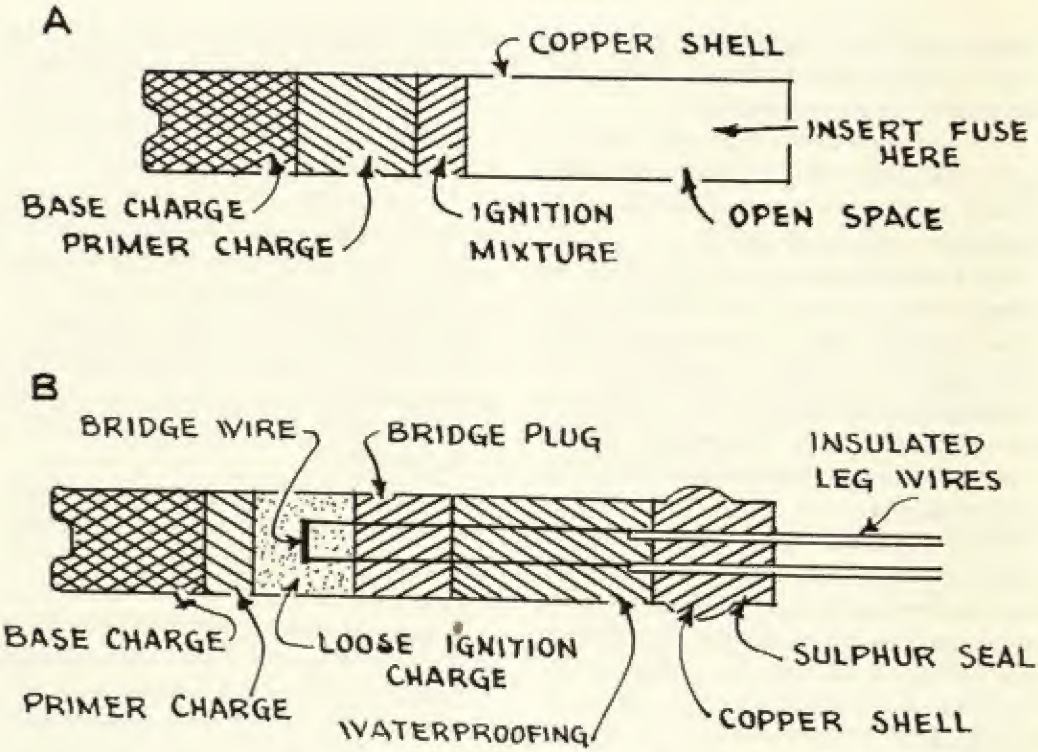


Fig. 9-3. Detonating caps

without incident, but there is always a chance that it may explode.

Spoiled dynamite may soak into its containers, and render them explosive. The cases and wrappings should therefore be burned with the same precautions as would be taken with dynamite.

The "ammonia" dynamites use ammonium nitrate as the principal explosive, in combination with some nitroglycerin. They do not catch fire as easily as straight dynamites, and are less sensitive to shock and friction. Water resistance is generally inferior, but fumes are less objectionable.

These are rated on a percentage strength basis, but the figures do not indicate anything of their chemical composition, but simply that performance is comparable to that of a straight dynamite of the same rating.

A third type of explosive used in commercial blasting is gelatin dynamite. This is based upon a jelly made by dissolving nitrocotton in nitroglycerin. Various other ingredients are added.

The gelatin dynamites are dense, plastic, cohesive, and practically waterproof. Fumes are excellent in all but the highest strengths, which vary up to ninety percent. A 100% gelatin is produced, but is not used in construction or mining.

Shot with a standard cap, and when not confined, ordinary gelatin dynamites will explode at a velocity of about 5,000 ft. per second. If confined, or shot with a straight dynamite primer, velocities of 13,000 to 22,000, depending on the strength, will be obtained. Certain types may also be obtained which will always detonate at the higher velocity.

Gelatin dynamites are relatively insensitive to shock, and often will not explode by propagation from adjacent holes. Their plasticity makes it easy to load them solidly in boreholes, and to pack tightly in cracks for mudcapping. The velocity of the higher

grades and their high density recommend them for hard, tight blasting; and the waterproof qualities for any underwater work not requiring propagation.

Ditching, stumping, and agricultural dynamites are usually one of the standard strengths best suited for the purpose, with a special designation.

Blasts are initiated or set off by timing devices, by remote electrical controls, or by a combination of these methods.

Safety Fuse. The original timing device is a fuse made up of a black powder core, surrounded by layers of protective wrappings. Two speed ranges are available, with burning speeds of ninety seconds and one hundred twenty seconds to the yard. These speeds must be considered approximate, as they are affected by altitude, weather, storage conditions, and possible damage to the fuse.

Fuse is water resistant except at the cut ends, which are immediately spoiled by contact with moisture. It should not be used unless it can be shot the same day it is loaded.

It is manufactured in lengths of fifty feet or more, and wound in coils or on spools to be cut to the desired length on the job. As short an interval as possible should be allowed between cutting and using.

Squibs. Electric squibs are devices for igniting charges of black powder, and may be used instead of fuses. They consist of copper or aluminum tubes with powder, an electric firing element, and wires sealed into them. They are imbedded in the powder charges, and when sufficient current passes through them, they take fire and ignite the charge.

Blasting Caps. Figure 9-3 shows the construction of blasting caps for both fuse and electric firing. Fuses are inserted in the hollow shell of the cap, and fastened in by crimping the metal with special tools or machines. The fuse should be cut off square, preferably by a razor blade or other very sharp edge, which will not pinch the wrappings together.

The electric firing device consists of a very thin wire lying in a highly combustible mixture. Passage of electricity causes the wire to become white hot and ignite the mixture, which explodes the primer and high explosive.

Delay firing may be obtained by use of delay electric blasting caps which have a slow burning composition between the ignition charge and the primer charge. Time interval is a half to two seconds in standard delay caps, and .025 to .1 seconds in the millisecond type.

Wires may be obtained in almost any desired length, and should be long enough to reach the wires from adjacent charges, or to connect with the lead wire to the electrical source. They may be copper or iron, and are protected by a plastic insulation. The ends of the wires are fastened together into a bridge or shunt, to prevent premature firing through contact with stray electric currents.

Instantaneous and delay caps may be used on the same round. If they are in the same series, it is well to increase firing current by ⅓. Caps made by different manufacturers should never be fired together. They are almost certain to have different current requirements, so that one brand of cap will fire and break the circuit before the bridge wires in the other brand are heated enough to fire.

Caps contain explosives which are more sensitive than dynamite, and they must be handled with great care. Heat, friction, and shock must be avoided. In the original package, electric caps are usually cushioned in their own folded wires, and are often protected by a cardboard or paper wrapper in addition.

The greatest danger of accidental explosion of caps comes from electricity. Even with their wires shorted, as in the original package, a powerful nearby cur-

rent may detonate them unexpectedly.

After the wires are separated for use, the danger from stray electrical current becomes very great.

The content of a cap is small, but one can blow off fingers and toes, and flying particles of the copper case may cause injury to personnel within a radius of thirty feet. The most serious danger in an accidental explosion of caps, however, is that of setting off nearby heavy explosives.

Caps should be buried before exploding for test purposes.

HANDLING EXPLOSIVES

Transporting. Large quantities of explosives should be transported in special vehicles marked in accordance with state laws. Smaller quantities may be carried in an ordinary car or truck, with any required warning signs made so that they can be removed when not in use.

Caps and explosives should be carried in different trips or vehicles, unless quantities are small, in which case they may be carried in one vehicle if kept well separated and if permitted by law.

ICC regulations are accepted by most states for intra-state transportation, but some have more restrictive laws.

Storage. Different classes of explosives should be kept in separate magazines. These should be far enough apart so that an explosion in one would not affect the other; and should be surrounded so far as possible by earth barricades or higher ground so that the force of an explosion would be deflected upward.

Magazine areas should be as far as practicable from roads, railroads, or structures, should be posted with warning signs and fenced if possible. A list of minimum distances will be found in the Appendix.

Magazines should be constructed of cohesive fire resistant material, such as sheet iron, or soft material such as brick which will tear or crush rather than separate into flying fragments. Ventilation and protection from grass fires and from excessive heat should be provided. Doors should be heavy and provided with strong locks.

Portable magazines to hold a few cases of powder or boxes of caps are most easily made from large metal tool or packing boxes fastened with padlocks. When properly marked, these are legal in most states, although many laws and regulations recommend more complicated units. When a portable magazine is to be left on a job, it should be chained and locked to a tree or other anchor.

Boxes. Dynamite may be packed in cases of either wood or cardboard. The cardboard can be readily torn open, but the wood presents a special problem.

Theoretically a wooden box should be opened by knocking the top off with a wood wedge and hammer, to avoid danger of setting off the dynamite by a spark from metal tools.

Actually, however, the top may be pried off with an ordinary screwdriver or pinchbar, with possible assistance from a hammer, with very slight danger. Care should be taken to get the tool between the nails rather than against them, and not to push it into the dynamite.

Some blasters open dynamite cases by smashing them against the ground or with hammers, but this practice is considered unsafe. No manufacturer will recommend use of any such rough treatment, and it is forbidden by many state laws.

The wood or cardboard from opened boxes may be explosive from fragments of dynamite sticking to them, or liquid from decomposing dynamite soaking into them. They are therefore unsafe for use as firewood, or to burn in close proximity to personnel or buildings.

Handling. Dynamite may cause severe headaches. This is especially apt to occur if it is unwrapped and handled with bare hands. Different brands and strengths differ

in headache producing qualities, and individual reaction is highly variable.

Persons handling explosives should not smoke and preferably should not carry matches. A complete list of safety precautions recommended by the manufacturers will be found in each box of dynamite. A few basic rules may be emphasized here:

1. Do not expose any explosive to flame, heat, sparks or electrical current, shock or friction, and do not load or handle them during a thunderstorm.
2. Do not use iron tools.
3. Do not keep larger quantities of explosives on hand than are needed.
4. Keep caps and powder as widely separated and as thoroughly protected from each other as possible.
5. Keep records of explosives on the job, and those used in each shot, and make sure no unexploded material is left lying around the job, or concealed where children might find them.

A complete list of the "Don'ts" issued by the Institute of Makers of Explosives is included in the Appendix.

DRILLING

The simplest type of drilling pattern is a straight line of vertical holes parallel to a vertical face. The distance from each hole to the face is called its burden, and the distance between holes their spacing.

The holes are drilled somewhat deeper than the face so that any ridges left between them will not project above the new grade.

Blasts tend to overbreak at the top and not shatter completely at the base. As a result, faces tend to slope back. The projection of the bottom beyond the line of the top is called the toe.

The extra burden at the toe may be handled by bottom drilling, or heavier loading (more powerful explosive or tighter packing) in the bottoms of vertical holes.

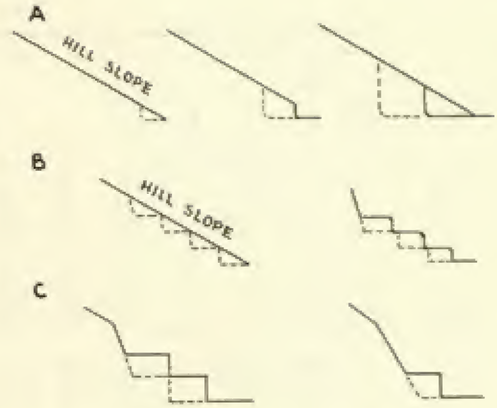


Fig. 9-4. High face and bench cutting

Face Height. A face may be a few feet or several hundred feet high. High faces are usually developed by pushing low or moderate ones back into a hillside, as in Figure 9-4 (A). Where the height can be regulated, it is more efficient to make a deep rock cut in a series of benches, or lifts, as in (B). These lifts are likely to be from ten to fifty feet in mines or quarries, and ten to twenty in road cuts.

Height affects the method of drilling and the size and placement of the holes.

In general, hand drills are used for depths up to ten feet, wagon drills from ten to thirty feet, and churn drills for higher ones. However, the lighter drills are often used to greater depths, particularly when access is difficult. The overlap zone of wagon and churn or rotary drills is in between 30 and 80 feet.

Hole Size. Hand drills will produce hole diameters of between 1″ and 2″, wagon drills 1½″ to 4½″, and well drills four inches and more. Hand and wagon drills with steel bits will produce holes tapering from the top to the bottom, and fairly uniform diameters with carbide bits. Well drill holes should not taper.

Burden. The explosive in each hole is supposed to break out a section of the rock between the line of holes and the face. Only experience with the particular rock

TABLE XXIV

Pounds of Du Pont Explosives per Foot of Hole—When Cartridges Are Slit and Well Tamped

Borehole Diameter Inches	Straight	"Red Cross Extra"	Gelatin	"Gelex" No. 1	"Gelex" No. 2	Du Pont "Extra" A	B	C	D	F	H	"Red Cross" Blasting Free Running No. 2	No. 3	No. 4	No. 5	"B" Blasting Powder
1	.42	.40	.47	.42	.38	.39	.37	.35	.34	.30	.26	.33	.32	.30	.29	.34
1¼	.64	.62	.72	.64	.61	.62	.59	.56	.54	.47	.41	.54	.50	.46	.45	.52
1½	.95	.91	1.05	.95	.88	.90	.85	.82	.78	.68	.60	.75	.72	.66	.65	.76
1¾	1.27	1.22	1.42	1.27	1.20	1.22	1.15	1.11	1.07	.92	.81	1.02	.98	.90	.88	1.02
2	1.65	1.58	1.84	1.64	1.54	1.57	1.48	1.42	1.36	1.18	1.04	1.35	1.29	1.20	1.16	1.32
2½	2.55	2.45	2.84	2.55	2.44	2.50	2.35	2.26	2.17	1.87	1.66	2.08	2.00	1.84	1.80	2.04
3	3.75	3.60	4.17	3.74	3.53	3.60	3.39	3.27	3.14	2.70	2.40	3.00	2.89	2.71	2.66	3.00
3½	5.10	5.28	5.68	5.08	4.62	4.91	4.62	4.44	4.27	3.67	3.26	4.08	3.93	3.62	3.53	4.08
4	6.60	6.83	7.35	6.58	5.90	6.27	5.90	5.68	5.46	4.70	4.17	5.28	5.13	4.74	4.65	5.28
4½	8.40	8.70	9.35	8.38	7.51	7.98	7.51	7.23	6.95	5.99	5.30	6.73	6.50	5.96	5.82	6.72
5	10.50	10.88	11.69	10.48	9.42	10.01	9.42	9.07	8.71	7.51	6.65	8.21	8.10	7.37	7.20	8.40
5½	12.6	13.07	14.0	12.58	10.60	11.26	10.60	10.20	9.80	8.45	7.49	10.1	9.68	8.90	8.70	10.1
6	15.0	15.55	16.7	14.98	13.57	14.42	13.57	13.06	12.55	10.81	9.58	11.8	11.5	10.6	10.4	12.0
6½	17.5	18.15	19.5	17.47	15.93	16.92	15.93	15.33	14.73	12.68	11.25	13.8	13.5	12.5	12.2	14.0
7	20.4	21.16	22.7	20.38	18.47	19.63	18.47	17.78	17.09	14.72	13.05	16.1	15.7	14.5	14.2	16.3
8	26.7	27.6	29.7	26.6	23.5	25.0	23.5	22.7	21.8	18.8	16.7	21.0	20.4	18.9	18.4	21.4
9	33.7	35.0	37.6	33.7	30.0	32.0	30.0	29.0	27.6	24.0	21.2	26.5	25.8	23.9	23.4	27.0
10	41.7	43.2	46.4	41.6	37.7	40.0	37.7	36.2	34.8	30.0	26.6	32.8	32.0	29.5	28.8	33.4
11	50.4	52.2	56.1	50.3	42.4	45.0	42.4	40.8	39.2	33.8	30.0	39.6	38.6	35.7	34.9	40.3
12	60.0	62.2	66.8	59.9	54.2	57.6	54.2	52.2	50.0	43.2	38.3	47.0	45.9	42.5	41.6	48.0

TABLE XXVI

Burdens—Number of Cubic Yards of Rock Displaced per Foot of Borehole

Average Burden on Boreholes	Spacing of Boreholes 6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
6	1.33	1.55	1.77	2.0	2.22	2.44	2.65								
7	1.55	1.81	2.0	2.33	2.7	2.85	3.11								
8	1.77	2.0	2.37	2.65	2.96	3.26	3.55								
9	2.0	2.33	2.65	3.0	3.33	3.66	4.0								
10	2.22	2.7	2.96	3.33	3.7	4.1	4.44	4.81	5.18	5.55	5.92				
11			3.26	3.66	4.1	4.48	4.88	5.3	5.7	6.11	6.52				
12				4.0	4.44	4.88	5.33	5.77	6.22	6.66	7.11				
13					4.81	5.3	5.77	6.26	6.74	7.22	7.70				
14					5.18	5.7	6.22	6.74	7.26	7.77	8.30				
15					5.55	6.11	6.66	7.22	7.77	8.33	8.88	9.44	10.0	10.55	11.11
16							7.11	7.70	8.30	8.88	9.48	10.07	10.66	11.3	11.85
17							7.55	8.18	8.81	9.41	10.07	10.70	11.33	11.96	12.59
18							8.0	8.66	9.33	10.0	10.66	11.33	12.0	12.66	13.33
19								9.15	9.85	10.55	11.3	11.96	12.66	13.37	14.07
20								9.63	10.37	11.11	11.85	12.59	13.33	14.07	14.81
21										11.66	12.44	13.22	14.37	14.77	15.55
22										12.22	13.03	13.85	14.66	15.48	16.30
23										12.78	13.63	14.48	15.33	16.18	17.03
24										13.33	14.22	15.11	16.0	16.88	17.77
25										13.88	14.81	15.74	16.66	17.60	18.51
26										14.44	15.74	16.37	17.33	18.30	19.26
27										15.0	16.15	17.0	18.0	19.0	20.0
28										15.55	16.6	17.63	18.52	19.7	20.74
29										16.1	17.18	18.26	19.33	20.4	21.48
30										16.66	17.77	18.88	20.0	21.1	22.22

NOTE:—To reduce to tons: For limestone, shale, granite, etc., multiply by 2¼; for trap rock, multiply by 2½; for sandstone, multiply by 2⅛.

Fig. 9-5. Loading tables

and explosive will indicate exactly the amount and type required.

In a general way, however, it may be said that a pound of 40 percent dynamite should break up and move two yards of soft rock, or one yard of medium hard rock, on an open face. In soft, layered, or rubbery rocks, 20 percent dynamite might move more per pound; while in very hard rocks, even higher strength dynamites might have smaller production. In tight holes, at edges, and in corners heavier loading is required.

Figure 9-5 (A) contains a table show-

ing the weight of dynamite of various types which can be packed per foot of hole, for various diameters. For tapered holes, the top diameter may be averaged with the bottom.

These figures are for free running dynamite, or cartridges which have been slit thoroughly, and are pushed down firmly with a tamping stick. If the cartridges are not to be tamped, one may be weighed, or the weight calculated from the number of them found in a fifty pound box. Most cartridges are eight inches long, and those weighing a half pound each would load at .75 pound per foot untamped.

The table in (B) gives the yardage of rock to be moved per foot of hole for various burdens and spacings.

As an example of the use of these tables, consider that a wagon drill will produce a hole with an average diameter of 2″ in a rock requiring a pound of powder for a yard. Table (A) indicates that 1.84 pounds of gelatin dynamite will be used for each foot of hole. This explosive will move 1.84 yards of rock, which according to Table (B) calls for seven foot spacing and a seven foot burden or eight foot spacing and a six foot burden. If the rock were soft enough to require only half a pound to the yard, spacing would be ten or eleven feet, and burden ten or nine.

It should be understood that Table A is only accurate for this make of powder, and that these calculations are meant only as a guide for trial shots, the results of which will indicate whether changed procedure is needed.

When a hole fails to move all its burden, it is said that it did not "pull." This usually occurs at the bottom of the hole, and most often in edge or corner holes where the rock is held back on two or three sides. Such failures may be due to too heavy a burden or too wide a spacing, to improper stemming of a shallow hole, use of the wrong explosive, explosive not reaching the bottom of the hole, or a partial misfire. It is generally necessary to remove the blasted rock, then drill and shoot the bottom again.

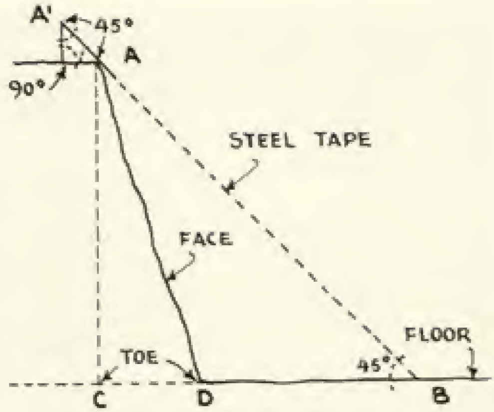


Fig. 9-6. Measuring face height

Measurement. In order to drill and load holes accurately, it is necessary to know the height of the face and the amount of the toe. With low faces, or in casual operations, or in working upper lifts to temporary grades, depths may be estimated, although this is always risky.

Faces between ten and seventy feet may be measured by the device and method shown in Figure 9-6. A 45° right triangle is carefully made of two by twos or two by fours, with the sides of the right angle equal and from two to four feet long.

This is placed on the top edge of the face, as shown, and the bottom carefully leveled. A sight is taken along the line A'AB and the spot B marked on the quarry floor by an assistant. The distance AB is then measured with a steel tape. Multiplying its length by .71 (the sine of 45°), gives the height of the face and also the distance BC. The distance BD is then measured, and when subtracted from BC, gives CD, the projection of the toe.

This measurement may be repeated at various points along the face.

If the face is high, its top irregular, or considerable accuracy is necessary, it may be preferable to make a transit survey of the site, establish benchmarks and loca-

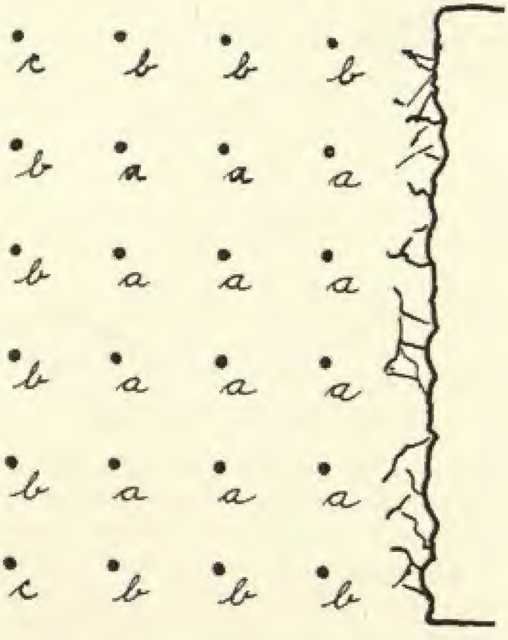


Fig. 9-7. Open and tight holes

tion points on all levels, and calculate from direct measurements from these points.

Each drill hole may be marked according to the cut to bottom grade, or by the drilling depth desired. For convenience in loading, the projection of the toe may also be noted on the marker.

Bottom Grade. The bottom grade should have a slope for drainage that may be away from the face or toward the sides, but not toward the face. If natural drainage is not possible, adequate pumps should be provided.

If blasting and excavating are accidentally carried below grade, hollows can be readily filled with fine shot rock. If the floor is too high, and the rock is soft, it may be possible to take it down with rippers and dozers. If it is too hard for machinery, a tedious job of shallow drilling and blasting is required.

Spacing. In general, large drill holes are increasingly prevalent in faces over 30 feet high, with proportionate increase in spacing and burden.

With most rock types, a point will be reached where enlarging and spreading the holes will result in poor fragmentation in the center of the blocks.

Faces fifty feet or more high are usually shot with a single row of holes at a time. Low faces use additional rows, fired simultaneously or in short-interval succession. In any height, holes in the same row are now fired in sequence.

Each blast should supply enough rock to keep the shovel busy for at least half a day, therefore, the lower faces must be shot back deeper than the high ones, particularly if the shovel is large and its working area narrow.

The entire group of holes may be drilled on a rectangular pattern, as in Figure 9-7, or they may be staggered to improve fragmentation.

Best results from multiple rows are obtained if there is a free cleavage plane at the new grade. If the bottom is very hard to pull, heavier loading may be required than when firing single rows; or burdens may have to be reduced progressively toward the back, resulting in higher costs.

Tight Holes. When blasted rock must be sheared away on two or more planes the shots are called tight. In Figure 9-7 the holes marked (a) are open, those marked (b) are tighter, having to shear off the back or side as well as the bottom, and the (c) holes must shear along back, side, and bottom. In general, the tighter the hole, the greater the likelihood that it will fail to pull. It is usually cheaper to take special precautions with tight holes in the original blast, than to do secondary drilling and blasting.

The tightest blasting found in open work is the start of a cut down from the surface. The first rock blasted can move upward only. If the whole set of drill holes are shot together, each of them will be very hard to pull. However, if the center holes are made oversize, loaded heavier, and

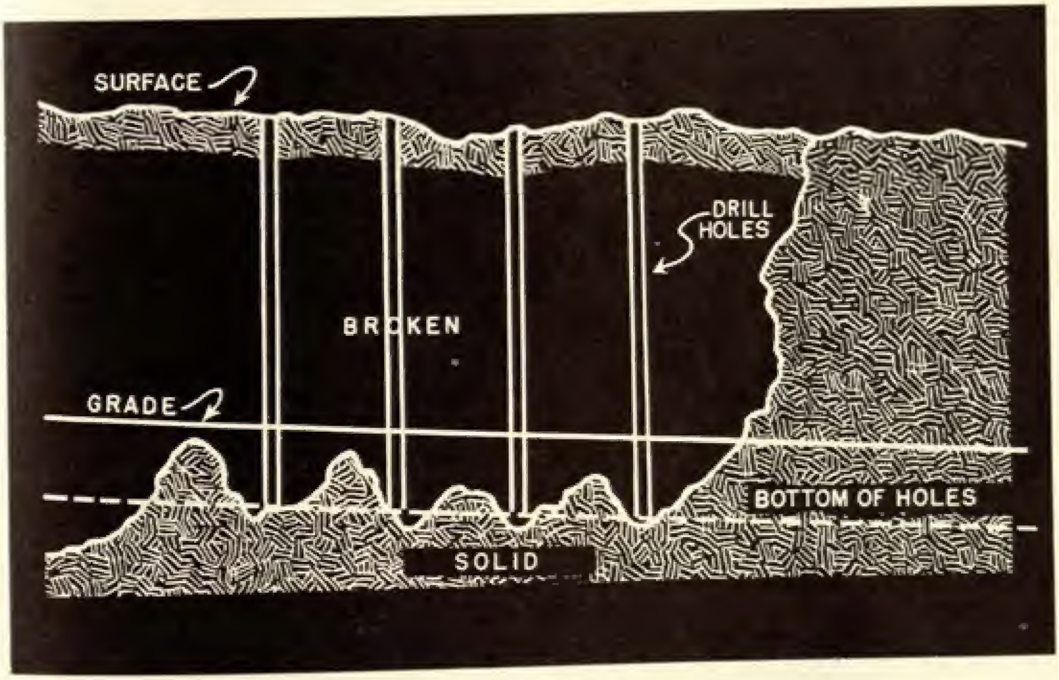


Fig. 9-8. Breakage lines

fired first in a delay sequence arrangement that progresses toward the outer limits of the area, the adjoining holes can throw into the space left, then the next holes throw into their space.

Overbreak. Rock usually tends to overbreak at the top of the bank, and special drilling or loading may be required to avoid leaving a hard bottom rib at each blast junction. See Figure 9-8.

It may be necessary to set back the first row of holes for the next blast for more than the normal burden, as their burden may be partly shattered, so that the shot is not confined as well as in the other holes. Drills may not be able to work close to the edge, or may not be able to penetrate shattered material.

In such conditions, the front row may not pull the bottom, unless it is drilled considerably deeper than the others, some horizontal bottom snake holes are drilled, or a denser or faster explosive is used.

However, shovels are frequently able to scrape away a few feet of unblasted soft rock, without excessive wear, in which case ribs may be ignored in the blasting pattern and dug out when found.

Short period delays have greatly improved the blaster's control over overbreak.

Delay Shots. Proper sequence of firing in a series of holes can be obtained by setting separate blasts, using fuses of different lengths, or of the same length lighted in a particular sequence; or electric firing with delay caps or a timed firing device.

Fuses become increasingly dangerous as the number in one shot increases, and they are not satisfactory where exact timing is required.

The standard delay caps are made in about ten different periods with an interval of a second or more between them. Shortest periods are put at the face, or in the spot selected for wedging or crushing "out of the solid." Destruction of the wiring by the first blast will not interfere with the explosion of later caps.

Long period delays are better than mass shooting or fuses, but have several

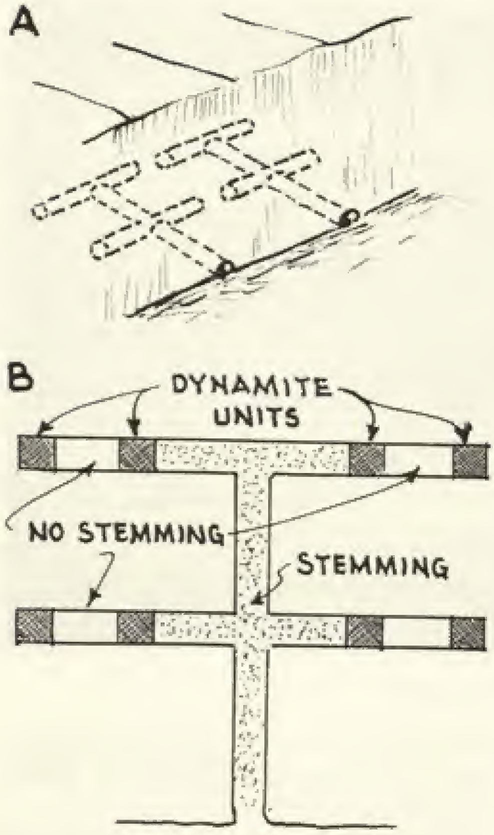


Fig. 9-9. Coyote holes

disadvantages. Overbreak by an early shot may take too much burden away from a later one, causing dangerous scattering of rock and excessive noise. The repeated explosions may set up a resonance in buildings or delicate equipment which will be more destructive than a single heavy blast. Caps of the same period may not explode at the same time.

Millisecond delay caps have intervals of fifteen to fifty thousandths of a second, and are obtainable in ten or more periods. A set will produce an explosion which seems to go up all together, but vibration and concussion are reduced, fragmentation is often greatly improved, and overbreak is reduced.

A timer may be used to obtain millisecond delays with instantaneous caps. An electric motor turns a cam which makes successive contacts with different firing lines. The time of the intervals is adjustable. However, a misfire will be caused if any wire is blasted out before firing its caps.

Edges. In road cuts, the side faces should be made as accurately as possible without the special precautions used for dimension rock. In general, it is cheaper to overblast than to do chipping, scaling, and secondary blasting to remove humps. The terms of the contract, particularly in regard to accuracy of surface and payment for overbreak, and the behavior of the rock will determine the methods used.

Precision in cutting a back or side wall may be obtained by the use of line drilling (edge holes drilled but not loaded), close spacing of blast holes along the finish lines, blasting it as a single line of holes, or as the last shot in a rotation series, and use of light shots and thin burden. Any one of these precautions may be sufficient or all three may be required.

Buffers. Blasted rock may be entirely dug away before the next blast, or varying quantities may be left against the face. Complete cleanup is required if the toe is to be accurately measured or drilled horizontally, and is considered good practice with high faces.

If the working space is narrow, and the face low, it may be desirable to leave some shot rock as a buffer or "blanket." This confines the force of the explosion, and may prevent blocking of the work area and aid fragmentation. However, the buffer should be small enough so that some scattering occurs, as this makes it easier to find and blast oversize rock before the shovel gets in the heap. Heavier loading is required.

Snake Holing. Sometimes a face can be most economically blasted from the bottom only. This may be when a cliff (face) is being cut into a steep hill with poor access to the crest, the rock has a vertical cleavage so that it will break away

without dangerous overhang when the bottom is blasted out, and is brittle enough to shatter when it falls. Such an operation may be very economical of powder, as the breaking out of the crest and fragmentation upon hitting the floor are accomplished partly by gravity.

Coyote Holes. Coyote holes, illustrated in Figure 9-9, are used for heavy undermining blasts. They may be used alone to topple a cliff, or to break out heavy toe burdens in conjunction with well drill holes loaded from the top. Faces should be at least 60 to 80 feet high to justify their use.

Coyote holes are used when material is difficult to drill, a large yardage is required at one time, and when the rock fractures readily.

They consist of small tunnels, three or four feet in diameter, driven horizontally into the face at floor level, and one or two cross tunnels parallel to the face. Explosives are stacked in the cross tunnels and the entrance is securely blocked with stemming. Firing is best done by Primacord.

LOADING

Holes may be loaded in a number of ways. These may be classified as solid, string, spaced, deck, and spring.

Solid. In solid loading, as much explosive is crammed into the hole as it will take. Usually, cartridges slightly smaller than the hole are slit and dropped or pushed into the hole, and then crushed with a tamping stick so that they will spread.

Two to four longitundinal slits may be made in the wrapper. This is a safer method than unwrapping because of the reduced danger of accidents from spilled powder, of headache, and because the wrapper ends protect the powder against rock chips and prevent sticking to the tamper.

The tamping stick should be of wood, round, of slightly smaller diameter than the smallest part of the hole, and cut straight across the working end. If the hole is too deep for the use of a single tamping stick, several sticks should be drilled lengthwise and strung together with a cord. When the cord is slack, the stick will fold and can easily be fed into the hole. If any stick is held, and the cord tightened above it, the joints below the pull will be made rigid.

If the lower end of the stick wears to a taper, it should be cut back. The taper may punch holes in the tops of cartridges that would not be filled by pressure on the next one placed, it may grind some of the powder against the sides, and it may stick in cartridges and pick them up.

Carlon E plastic pipe plugged at one end can also be used for tamping.

No exposed metal of any kind should be used in a tamping stick. Even the nonsparking metals such as brass and aluminum are definitely dangerous.

Tamping. Best compaction is obtained if each cartridge is tamped separately with a firm pressing stroke. Sharp blows should be avoided.

Large blast holes made by well drills are usually tamped with a block on the end of a rope. The block should be of hard wood to resist abrasion, be slightly smaller than the bore of the hole, and have a flat end.

If weight is needed for heavy tamping, or working in wet holes that would float wood, the block may be drilled and weighted with lead or other heavy metal plugs, which should be covered with wood.

This type of block is not adapted to ramming down cartridges which have stuck in the hole above the bottom, as it may cause excessive side friction. A special block with a chisel point stake that will break up the stuck cartridges, is better.

These blocks are shown in Figure 9-10.

Deep Holes. It is a good plan to check a deep large bore hole before loading it, by inspecting it with a flashlight or sunlight reflected from a mirror, or sounding it with a tamping block, to make sure it is not ob-

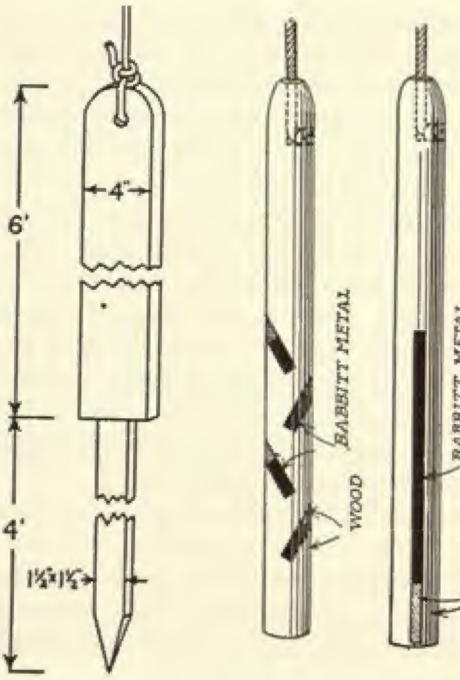


Fig. 9-10. Tamping and cutting blocks

structed. The block can be used to knock obstructing pieces or scale to the bottom.

Cartridges may be dropped into shallow holes or deep smooth ones. If the hole is deep and rough, and there is a possibility that they may stick part way down, they should be lowered. All explosives manufacturers will provide cartridges equipped with means to attach a lowering rope. A band of special Scotch Tape and a readily disengaged hook are used.

The impact of the cartridges on the bottom and the weight of the column above, frequently compress charges well enough so that tamping is not necessary.

If the hole is ragged or partially caved so that it is not practical to load it with cartridges, a free running dynamite may be poured down it. If it blocks the hole and starts to build over an obstruction, it should be poked down with a long jointed pole or a dislodging block.

If such a hole is wet, it may be necessary to use a gelatin dynamite unwrapped and cut into fine pieces and pored into it.

A tamping block used for unwrapped dynamite should be kept clean by resting it on a box or some sacks when it is not in use.

String. If the borehole is wet enough so that slit or unwrapped dynamite would be spoiled, or if solid loading would make too heavy a charge, cartridges somewhat smaller than the borehole, but not small enough to fit side by side, may be dropped in one after the other without tamping, or after having tamped the bottom cartridge or two.

This is the easiest way to load, and is satisfactory for small or occasional blasts. However, it is inefficient in that part of the hole is wasted, so that more rock must be drilled than is actually necessary to accommodate the amount of powder required for the blast.

Spaced. Spacers may be used to string cartridges out along a hole that is not to be fully loaded. These may be square, round, or hollow pieces of wood, tile, lean concrete, or rolled cardboard. They are usually made up ahead of time, in lengths of eight to ten inches. There should be sufficient air space around them to enable the cartridges to set each other off by propagation.

Spacers may be alternated with cartridges or pairs of cartridges in the parts of the borehole that are not to be fully loaded. The primer cartridge should have at least one additional stick in contact with it.

Decking. In large boreholes, charges which are to be strung out are usually separated by solid plugs of sand or other stemming material, and each section of the charge primed separately, unless fired with Primacord or other detonating fuse.

Figure 9-11 illustrates well drill holes showing a solid column load (A), a deck load (B), designed to blast a heavy toe and relatively thin top burden, and a deck load

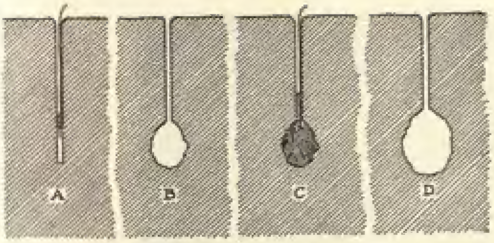


Fig. 9-12. Springing a hole

(C) which avoids danger of blowing out a mud seam.

Springing. If the force of a blast is to be concentrated at the bottom or back of a hole, it may be necessary to make an enlarged chamber to hold extra explosive. This is done by exploding a small quantity of dynamite—one to six cartridges for a two inch hole—in the bottom. The hole may be left open, or lightly stemmed with dry sand, or with water. Quick acting dynamite is used. The charge must not be large enough to blow out the face.

Springing makes a cavity by crushing the surrounding rock and blowing it out of the hole. Two or more blasts of increasing size may be required to make a large enough chamber. See Figure 9-12.

The explosion creates considerable heat which is slow to dissipate. Unless the hole fills with water, several hours should elapse between a spring shot and further loading. This time may be reduced, and the cavity cleared of loose sand and chips by lowering drill steel or air hose to the bottom and blowing it out with compressed air.

Sprung holes are most easily loaded with free running dynamite which can be poured in. If this is not available, slit, cut, or unwrapped cartridges can be spread into the chamber by tamping. The chamber will not fill, even with free running powders, unless thoroughly tamped.

Sprung holes are not advisable where the burden is light, or the rock tends to fracture readily along joints or bedding planes. The springing blasts may loosen a

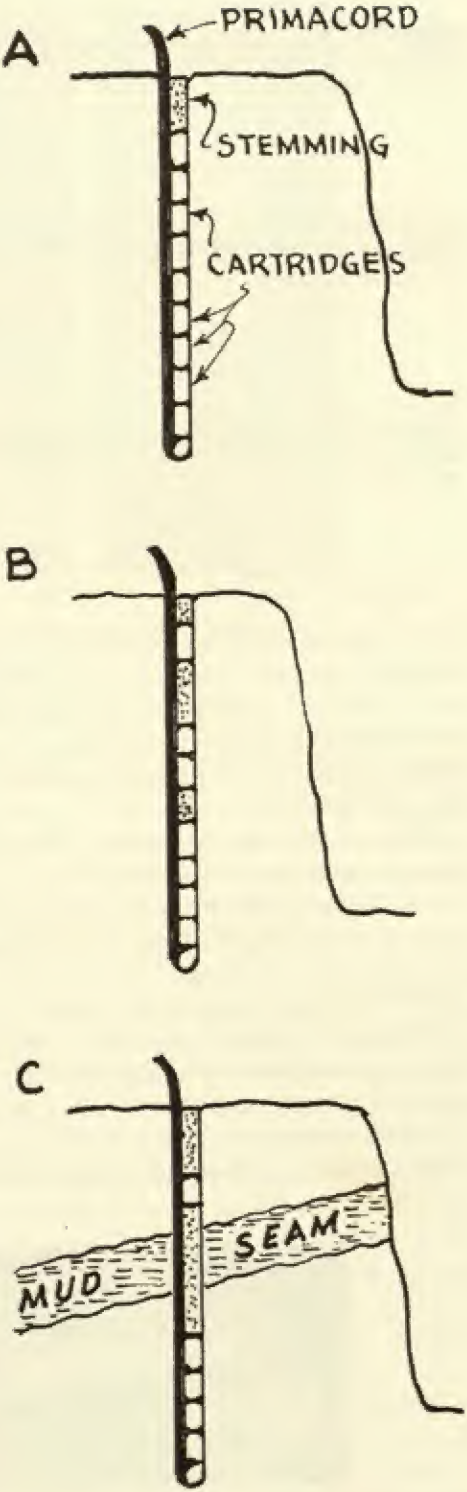


Fig. 9-11. Loading deep holes

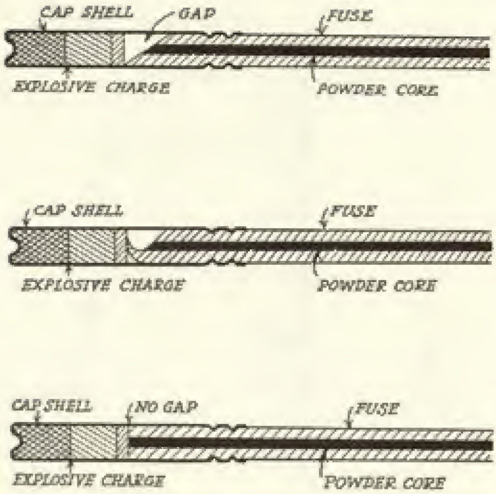


Fig. 9-13. Insertion of fuse in cap

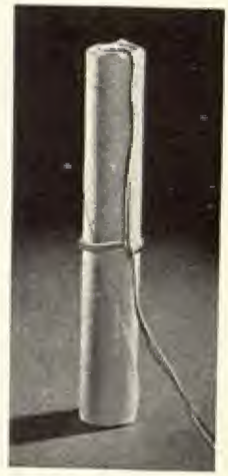


Fig. 9-15A. Priming small dynamite stick

slab of rock so that it will be thrown a long distance by the main blast. Such loosening can be kept to a minimum by using the fastest dynamite obtainable. Springing is becoming obsolete, as it is laborious, dangerous and inefficient.

Holes should not be sprung next to loaded holes because of propagation.

If springing blocks the hole, it can generally be re-opened with a drill or steel bar.

PRIMING

Primers. A primer is a stick of dynamite that contains a blasting cap; or is any other heavy explosive which has been fitted with a device for setting it off.

Since primers combine the power of the dynamite with most of the sensitivity of the cap, they must be handled with greater care than any other units of explosives.

They are ordinarily prepared at the borehole immediately before being placed, but may be made in some central place and delivered to the loaders as required.

The essentials of a good primer are that the cap must be powerful enough to produce detonation, there must be intimate contact between cap and explosive, they must be fastened together so that they will not separate while being placed, the cap should be shielded from shock or friction, and the wires or fuse should not be kinked or strained.

Black Powder. Black powder may be

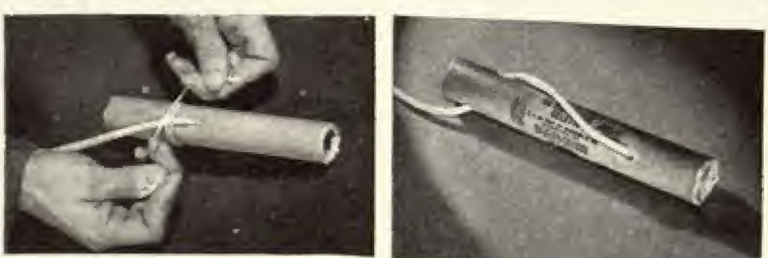


Fig. 9-14. Priming dynamite with fuse cap

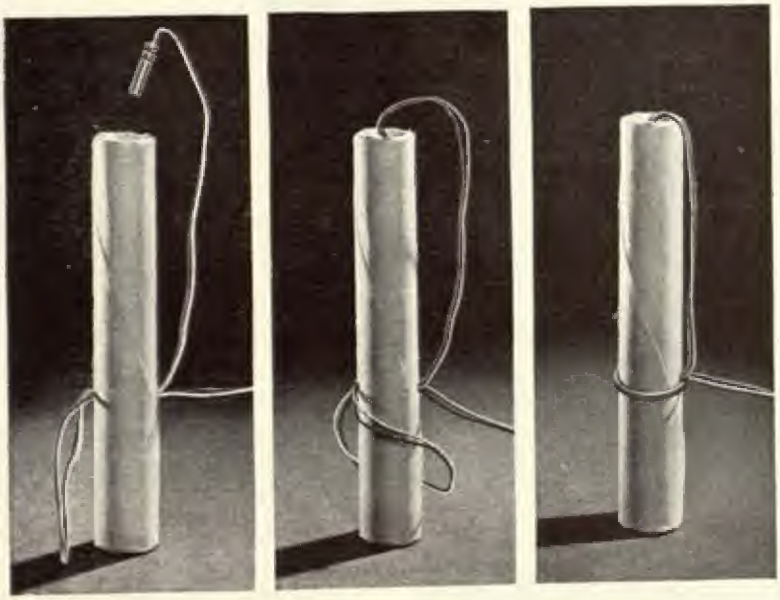


Fig. 9-15B. Alternative method of priming small dynamite stick

primed by placing a fuse in the hole and pouring the powder around it. This method may be improved by tying a knot in the end of the fuse to anchor it, and making several slits into the core above the knot where they will be in contact with the powder. A paper cartridge may be prepared to hold powder closely around the knot and slits.

If the powder is to be exploded by an electric squib, a similar cartridge is made up to enclose the squib with some powder.

Blasting caps may also be used to explode black powder.

Fuse Caps. Preparation of dynamite and fuse cap primers includes two jobs—attaching the fuse to the cap and the cap to the powder. The fuse ends MUST be dry.

The fuse should be cut squarely with a clean, sharp blade, preferably a razor blade in a suitable mounting, and pushed into the cap until it is seated against the explosive compound. The copper shell is then crimped firmly onto the fuse with a hand or a bench crimper.

If the fuse is cut on a bevel, it may fail to make a proper contact, as in Figure 9-13 (A), or part of the casing may curl over and prevent contact. A good contact is shown at the bottom.

The interior of the cap should be clean. Any foreign matter in it should be tapped out or removed with a straw or toothpick. Blowing into it may dampen it and cause it to fail. If the cap is suspected of being damp from any cause, it should not be used.

Figure 9-14 shows two ways to place and fasten a fuse cap in dynamite. In each case a hole or slit is made in the cartridge and the cap inserted. The primer can be held together by lacing the fuse through another hole, or by tying it with string.

In shallow holes, and in blockholing or mudcapping, it is practical to simply insert the cap in the cartridge end, without fastening, as the primer need not go out of reach. Friction will hold it in place against a moderate pull, but not against yanking.

Electric Cap Primers. Figure 9-15 illustrates the most common method of priming a small diameter stick of dynamite. The cap is pushed into the navel-like end of the wrapper and the wires caught in a half hitch around the center. If the dynamite is hard,

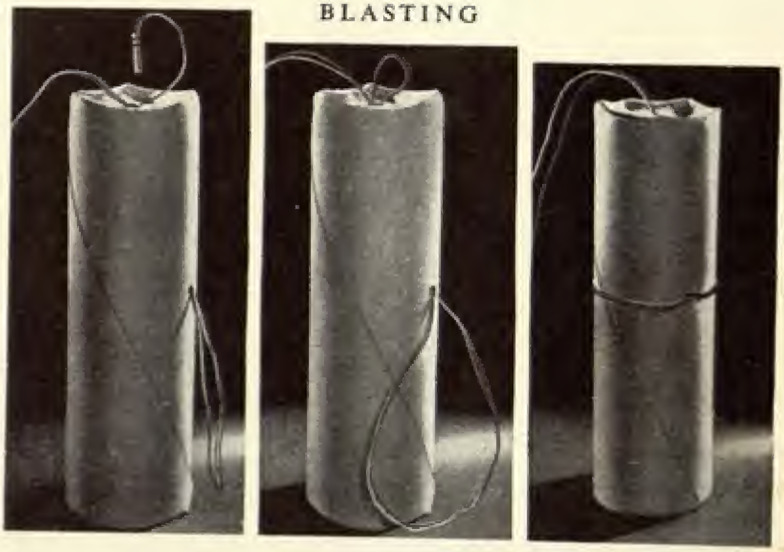


Fig. 9-15C. Priming a large stick of dynamite

a hole may be made in the end with a wood peg to make it easier to insert the cap securely so that it will not slip out during loading.

Figure 9-16 shows steps in a method which involves placing the cap in the same manner, but passing a loop of the wires through a cross hole punched in the center of the stick. This eliminates a slight danger of damaging the wires in the half hitch, but is somewhat slower to make up.

Large diameter sticks are best primed by the sequence shown in Figure 9-17. The cap is inserted in the top, and a loop of wire is pushed through a slanting hole and is caught around the middle.

In each case the cap is entirely inside the dynamite, cannot work into a position where it might scrape the side of the borehole, and its direction of explosion, away from the wires, is directed into the dynamite.

Primacord. Primacord is a detonating fuse, composed of wrappings around a core of PETN, a very high velocity explosive. It is insensitive to fire, friction, and ordinary shock, is waterproof except where cut, and does not deteriorate in storage. It is made in plain, reinforced, and wire-bound constructions. The plain type is used chiefly in trunk lines; the reinforced for ordinary branch lines, and the wire bound for branches which go down boreholes which are deep, or have ragged sides.

Primacord is detonated by either an electric or a fuse cap and will set off any ordinary explosive with which it has contact. It is usually attached to the first cartridge placed in the hole so as to fire each stick in the column by direct contact. Wet sections will explode if detonated from a dry end with a regular cap, or from a wet end by a special Pentolite cap.

It may be threaded through the cartridge or attached as a lowering line to a net or cartridge. For this service, the wire bound type should be used because of its greater strength. The rest of the load is slid or lowered alongside the Primacord.

Any secure method of fastening is satisfactory for small diameter sticks. Bindings should be tight enough to cut into the Primacord wrapping.

Pieces are spliced together where necessary by square knots. Branch lines should be fastened at right angles, except that no knots can be used in boreholes. They form an obstacle to smooth loading, and water penetrating the knot end of the lower piece would make it insensitive.

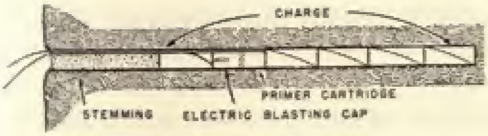


Fig. 9-16. Loading with instantaneous cap primer

Placing Primers. If one primer is to be used in a borehole, it is best to place it at the top, or one cartridge down from the top. This keeps to a minimum the danger of damage to fuse or wires while placing and tamping the charge. Use of one stick above the primed one cushions the primer against jars from overzealous tamping, and from contact with abrasive stemming material.

If the hole is long, or the charge heavy, it may be considered a good precaution to use two or more primers. The second one is liable to be in the bottom and any additional ones spaced throughout the column.

With all types of delay firing the primer must be in or near the bottom. This largely avoids the danger of throwing the primer out in the muck pile, where it would be likely to detonate during loading, with disastrous results.

Spaced charges are more likely to require additional priming than solid ones. Deck charges need a primer in each level.

Correct placing of primers, and even correct direction of the cap in the primer, are of importance under some circumstances and make little difference in others. Because of the speed and destructiveness of blasts, exact analysis of the mechanism and results are difficult.

Speed of Explosion. There are four classes of speed concerned in the firing of explosives. There is the slow burning of a fuse, the rapid burning of black powder in bulk, the extremely rapid detonation of high explosives, and the practically instantaneous movement of electricity through wire.

The point of ignition of a long column of

Fig. 9-17. 700 ton blast recorded by camera

black powder will have a definite effect on its work. Burning speed is between 1,000 feet and 3,000 feet per second, so that it would take ⅕th to $\frac{1}{15}$th of a second for a 200 foot borehole to fire. If ignited at the top, the upper rock might be moved a considerable distance before the bottom fired. In one way, this would act to lighten the bottom burden and help it to pull, but it might also serve to "uncork" the borehole and allow the bottom of the charge to blow upward rather than horizontally. On the other hand, the force of the upper part of the explosion, reacting against a heavy burden, might press down on the unexploded charge with great force and seal it.

If the column were set off from the bottom by electricity, the toe would be well kicked out before the explosion reached the top. If several caps were placed at intervals in the column and fired together, the

whole burden would be moved out at approximately the same time.

The same action is found in high explosives, although the rapid detonation makes it of less effect. A two hundred foot column of a 40 percent dynamite with a velocity of 10,000 feet per second, fired from the top, would explode at the bottom $\frac{1}{50}$th of a second afterward. If Primacord were used to the full depth, the detonation would take only $\frac{1}{100}$th of a second. If electric caps were used at top and bottom, the time at the bottom would be about $\frac{1}{5,000,000}$th of a second after the top, but the lag to the center would be $\frac{1}{100}$th of a second.

At first glance, these small fractions of a second might not seem significant. In many cases they are not, but they sometimes have an important effect on both the performance and the concussion of a blast.

If long borehole blasts do not give the desired effect in fragmentation, throw, or in any other way, it may be advisable to change the location, number, or type of primers to try for better results.

Cameras can be obtained that will take pictures of the various stages of the explosion for study.

Precautions. Precautions to be observed in regard to a primer in placing and leaving it in the hole include: placing it in such a manner that it is not subject to shock or jar, and is not penetrated by rock splinters or other sharp objects; that it is not to be wet for a longer time than the powder, the cap, the fuse, or the wiring can stand; that the fuse and wires lead to the top without kinks, and are held so as not to be damaged by placing and tamping of additional charges and stemming.

Water Resistance. Except for the gelatins, dynamite has variable water resistance, and may depend on its wrappings for protection. When the wrapper is punctured to insert a cap, water can enter the break. Speed and extent of damage, if any, will depend on the composition of the dynamite.

Until recently, waterproofing of standard caps would be apt to fail under water pressure in the bottom of deep holes. The cotton countered (wound) type of wire insulation was not satisfactory for wet work unless the wires were enameled.

Modern caps are sealed with rubber plugs and will stand up to 1,000 feet head of water, as will the plastic insulation on their wires.

LIGHTING FUSES

The length of fuse determines the time which will elapse between lighting it, and the explosion. Regular sequences of firing can be obtained by varying the lengths of fuse in different holes, and lighting them at the same time.

Fuse does not light readily with a match because of the small area of powder exposed, and the likelihood of wax from the coverings being spread over the end while it is being cut.

If only a few fuses are to be lit, good results can be obtained by splitting each fuse with a knife or razor blade, as in Figure 9-18, and bending the fuse so that the opening is down. It may then be lit with a match.

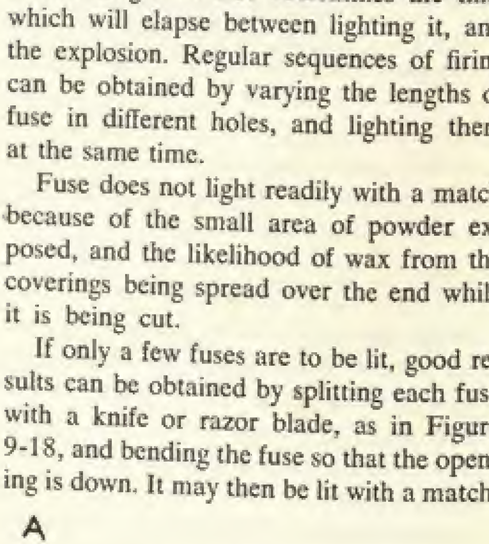


Fig. 9-18. Lighting a fuse with a match

Care should be taken to keep the fingers out of a line with the end of the fuse, as it will spit out a jet of flame.

The split fuse can be ignited more readily by having the opening horizontal or upward, placing a broken-off match head between the halves, and squeezing them together, as in (B). The match head gives a much hotter flame than the stick.

It is possible to buy a number of devices which simplify the lighting of fuses. The match lighter is a short paper tube which fits over the end of the un-slit fuse and is coated on one end with a compound similar to that of a safety match head. This is readily ignited with a match or the edge of a match box and subjects the fuse end to intense heat.

This lighter throws a jet of flame which resembles that caused by ignition of the fuse. To tell whether the fuse is actually burning it is necessary to observe a moment later whether a thin stream of smoke is issuing from it. If it is not smoking the lighter should be removed and another applied.

The pull wire lighter is of similar material, but clamps on the fuse and is ignited by pulling a wire.

The lead spitter is a coil of thin lead tubing containing black powder. A piece is cut off, lit with a match, and the resulting hot flame used to then light the fuses. The lead melts back as the powder burns.

The hot wire is similar to a fireworks sparkler. It burns slowly with a very hot flame, and is the safest and most dependable of the devices listed.

A fuse will light black powder by contact. When used to explode dynamite, it is connected to an explosive cap.

ELECTRICAL FIRING

Electrical firing requires a complete circuit from the power source through all the caps and back to the power source. One cap, or several hundred, may be used.

Source of Current. The standard source of electrical energy for blasting is a blasting machine. This is a generator, which delivers a high voltage current when a handle is twisted or forced down. Twist handles are ordinarily used only for small machines with a capacity of a few caps.

These devices are rated according to the number of caps in series which they can fire at one time. Rating is usually conservative. Their efficiency should be tested occasionally, particularly if they are not in steady use, as they may deteriorate rapidly in damp storage. Testing is done by means of a special rheostat which sets up a resistance in the line; and from one to four blasting caps. If the machine will overcome the rheostat resistance of its rated capacity, and fire the caps in addition, it is in good condition.

Blasting current may also be supplied from any source having sufficient voltage, as "high lines," storage batteries, or dry cells.

An electrical timer is available for use with high lines. It has a number of circuits which are fired in rapid succession by a cam driven by an electric motor. A gear transmission permits a choice of intervals from .010 to .025 seconds. This permits use of delay firing techniques with instantaneous blasting caps.

Series. There are three basic types of circuit—series, parallel, and parallel series.

When the caps are arranged in series, Figure 9-19, the current must have enough force, or voltage, to overcome in succession the resistance of the lead wire, the caps and their wires, and the return lead wire, in addition to the variable resistance offered by connections between wires.

Portable hand-operated electrical generators called batteries or blasting machines are used by many blasters. These are designed to explode a specified number of standard blasting caps in series at the end of five hundred foot lead wires, with surplus

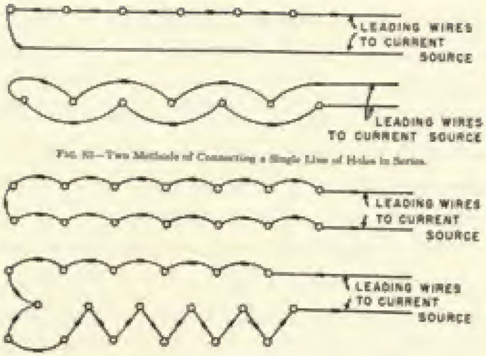


Fig. 9-19. Series wiring

power to overcome ordinary losses in connections and by ground conduction.

The use of one of these with the rated number of caps avoids the necessity of calculating the power necessary.

For most blasting purposes, connection to a "high line" or domestic type electrical generator with 110 or 220 volts will provide ample power. Voltages up to 440 are commonly used.

If dry cells, storage batteries, or other low voltage apparatus are to be used, or if the shot is very large, the voltage required can be calculated by Ohm's law.

Ohm's law states that the current, in amperes, in an electrical circuit will be equal to the potential, or voltage, of the power supply divided by the resistance, in ohms, of the circuit. That is, if sufficient current is supplied at 110 volts to a circuit with ten ohms resistance, the flow of current will be eleven amperes. If the voltage is six, the flow will be only .6 amperes.

A single cap requires a current of about .5 amperes. A series of caps takes 1.5 amperes, with sufficient voltage to overcome all resistances in the circuit.

The tables in Figure 9-20 indicate the resistance of caps and wires commonly used. The supply of current should be well over the calculated need, however. Minute differences in the bridge wires in caps may vary their resistance, so that a weak current might burn some of them through and break the circuit before all are exploded. An ample current should detonate them simultaneously.

Series circuits are easy to lay out, to hook up, and to test.

Caps made by different manufacturers must not be used in a series, because of variation in current requirement for detonation.

Parallel. In a parallel circuit, Figure 9-21, the current does not go through the caps one after another but through all of them at the same time. A poor connection on a cap wire affects only that cap. The voltage requirement is lower than when the same number of caps are shot in series, but more amperage is needed.

Two caps in series have twice the resistance of one cap. Two in parallel have only half the resistance of one, as less potential is required to force the current through a large conductor than a small one. But where 1.5 amperes was sufficient current

AWG Gauge No.	Ohms per 1,000 Feet	
	Copper	Aluminum
0	0.100	0.161
2	0.159	0.256
4	0.251	0.408
6	0.403	0.648
8	0.641	1.03
10	1.020	1.64
12	1.620	2.61
14	2.580	4.14
16	4.10	6.59
18	6.51	10.50
20	10.40	16.70
22	16.70	26.50

TABLE XIV
Resistance of Electric Blasting Caps in Ohms per Cap

Length of Wire in Feet	Copper Wire		Iron Wire	
	Instantaneous Caps	Regular and "MS" Delay Caps	Instantaneous Caps	Regular and "MS" Delay Caps
4	0.94	1.30	1.71	2.19
6	1.00	1.54	2.11	2.59
7	1.04	1.60	2.51	2.79
8	1.07	1.63	2.51	3.09
9	1.10	1.66	2.72	3.20
10	1.13	1.69	2.92	3.40
12	1.20	1.78	3.32	3.80
16	1.32	1.90	4.13	4.61
20	1.45	2.01	4.94	5.42
24	1.58	2.14	5.75	6.23
30	1.41	1.98	6.96	7.44
40	1.63	2.19	8.98	9.46
50	1.83	2.38	11.00	11.48
60	2.03	2.58	....	....
80	2.43	2.99	....	....
100	2.83	3.39	....	....
150	3.84	4.40	....	....
200	4.86	5.41	....	....
300	6.86	6.43	....	....

Fig. 9-20. Resistance of caps and wires

to shoot a whole series of caps, .5 amps is required for each cap placed in parallel.

Parallel wiring is therefore preferred where a source with low voltage and high amperage, such as a storage battery, is to be used. It is not suitable for blasting machines and the results with dry cell batteries are doubtful. High lines are equally efficient with either arrangement.

The most common simple parallel hookup is the second one shown, and it is not recognized as such by many who use it. It is the most convenient way to fire a small irregular group of blasts.

In figuring a parallel circuit, the resistance on one cap is divided by the total number of caps, and in a large blast, may be so small a figure that it can be ignored. The resistance of the two bus wires, between the leads and the last cap, is approximately one half the resistance of the same length of the same wire used for a lead. Lead wire resistance is the same as in a series circuit.

The lowered resistance of the bus wires is due to the fact that some of the current is diverted at each cap. Full current is present at the beginning, and zero current at the end, so that it averages out to about one half current for the full length of these wires.

Parallel Series. This layout, Figure 9-22, makes it possible to shoot large numbers of caps without requiring excessive voltage or amperage.

There is some disagreement about the balancing of the size of the different series. Technically, each series should have the same number of caps. Many blasters, however, claim better results when the series differ from each other by a set amount. This is said to be particularly advantageous when firing an excessive number of caps with a blasting machine.

When the series are equal, and juice put in the line, all caps are equally heated and should detonate simultaneously. If any

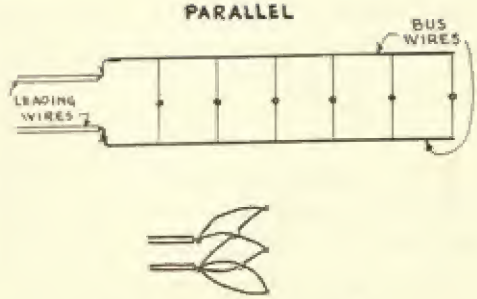


Fig. 9-21. Parallel hookup

series gets current but less than its share, due to a poor connection or other defects, it may not fire. However, as the other series fire, current will cease to go through them, and will all go through the remaining one, unless the wires are broken, until it fires also.

If the series have different numbers of caps, at first the current will flow most strongly through the series with the fewest caps and least resistance, and having fired that, will concentrate on the next longer string, and so through the whole group. If the current is weak, there may be a brief but definite time interval between the series, so that short strings should be at the face. If it is strong, explosions may be simultaneous.

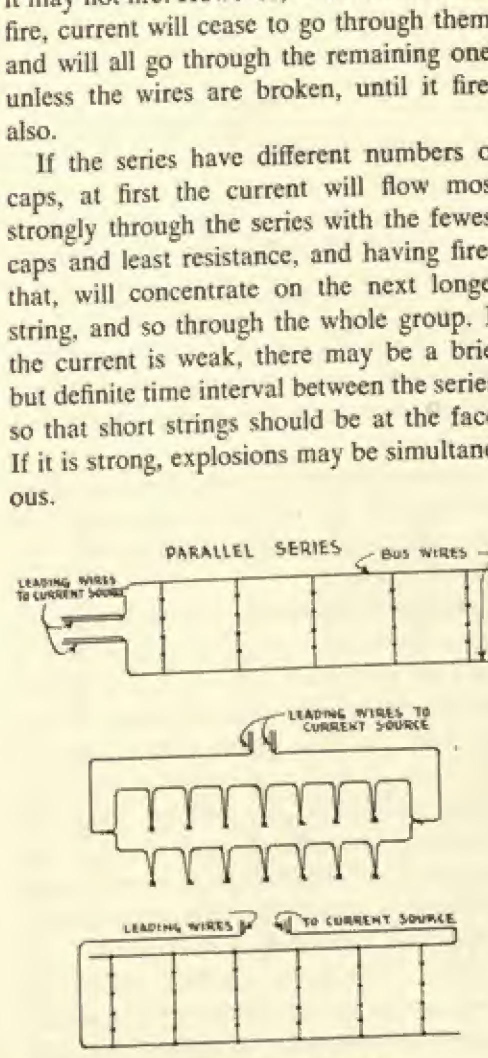


Fig. 9-22. Parallel series

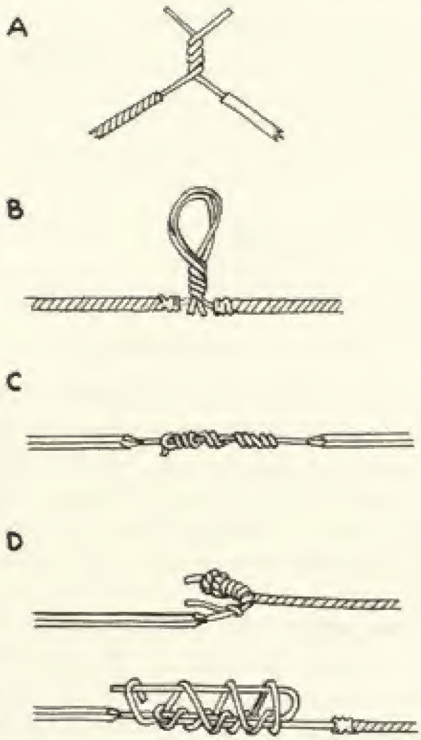


Fig. 9-23. Connecting wires

As the current from a blasting machine flows very briefly, it is possible that in a graded pattern only the shorter series would fire.

In most blasting patterns, the equal series hookup will be very much simpler than the graded series, which is generally considered obsolete.

Making Connections. It is most convenient to have the cap wires of such length that they meet each other with a moderate amount of slack between the holes. If they are short, an extra piece of wire must be spliced in at each connection; if they just reach, insulation or primers may be strained while splicing; and if much too long, they will need cutting, or will make a tangle of loose wire that may lead to mistakes in connecting, and accidents.

While connections are being made, the power or far end of the lead wires should be fastened together to ground out any induced current. The electrical source should be locked or at least removed from the immediate vicinity of the wires.

In a series circuit, the current runs from one lead wire through all the caps and their wires, to the other lead wire. The insulation on each lead is stripped back with a knife or plucked off with pliers for an inch or two, and the wire is bent into a tight loop.

The cap wires are pulled apart at their soldered connection, and each wire connected to one from an adjoining cap. When all the caps are connected in this manner, the two end wires are connected to the lead. Figures 9-23, (A) to (C), shows connections commonly used between caps, and (D) two cap-wire-to-lead-wire hookups.

It is usually possible to arrange the circuit so that it is convenient to hook both end caps to the lead. However, in a one row straight line layout, an extra wire must be used to connect the last cap to the lead.

If cap wires are long, such connecting wires are usually made up of scrap wire left from preceding blasts. It is good practice to extend the leading wires some distance with a lighter and less expensive wire, to reduce damage to the ends. If not enough surplus wire is available, connecting wire may be brought on the job on a spool and cut as needed.

The use of scrap wire involves a risk of misfires due to breaks inside the insulation, which is not justified by the small value of the wire saved.

When the last cap is connected, the whole series should be rechecked, to make sure that no hole has been omitted, that no loose ends of wire are lying around, and

Fig. 9-24. Protecting caps against stray currents

that connections are tight. It is good practice to squeeze each connection with pliers at this time.

Bare connections may be propped up on sticks or rocks where necessary to keep them out of water, or from contacting wet ground. If any connections are unavoidably wet, they may be tightly taped or smeared with water resistant grease.

If the shot is only of a few caps in a limited area, and the electrical source is of ample power, precautions against bare wet joints are necessary only if the water has a high mineral content.

Electrical Hazards. Electric caps are supplied with a connection between the ends of the wires which is called a shunt. This prevents the accidental building up of opposite electric charges in the two wires, which might pass enough current through the cap to explode it.

Such charges may be caused by the near presence of electrical machinery or transmission lines, a radio transmitter, stray currents in the ground, thunderstorms, or static electricity from dust storms or escaping steam. Such currents in lead wires may often be detected by inserting a No. 47 radio pilot lamp in the circuit instead of the cap. If it glows, conditions are unsafe.

The best precaution to take in blasting near an electrical hazard is to use fuse caps and Primacord. However, certain precautions can be taken which will reduce the danger of using electric caps.

Lead or other wires should not run parallel to electric lines.

The shunts should be left on cap wires until they are connected into the blasting circuit, and the circuit should be shorted until ready to fire.

The two-cap layout in Figure 9-24 illustrates the method to be used. The lead wire is shorted at each end. A wire is connected to one lead, and to one leg of a cap. A connection is made from the other leg or the shunt, to one leg of the next cap which has its other leg connected to the return lead. Making cuts where indicated will include the caps in a firing circuit which is closed until the leads are separated at the battery end.

Even with these precautions, however, blasting should be discontinued if there is a thunderstorm within five miles, or other severe hazards exist.

A portable battery-type radio (not FM), left at high volume, is an excellent warning device for the approach of a thunderstorm.

Testing. A circuit tester should be used for checking before attempting to blast. This device consists of a galvanometer and a silver chloride dry cell, which produces a current too weak to fire a standard blasting cap. The lead or cap wires are fastened to its terminals, and the action of the indicator needle shows the condition of the circuit.

If the circuit is good, the indicator needle will move an amount inversely proportional to the resistance offered by the caps and wire used. If the needle does not move, there is an open break. If it moves only slightly, a loose connection, or a break with

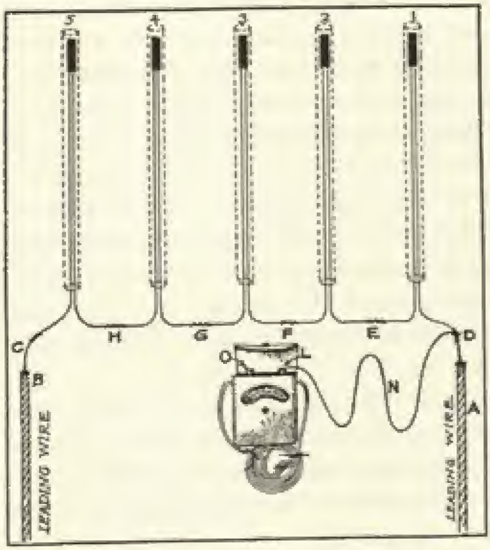


Fig. 9-25. Testing for break in blasting circuit

wires just touching, is indicated. If the needle moves farther than it should, a short or a ground is present.

A single test may be made from the power end of the lead wires when wiring is complete, or each hole may be tested before hooking into the circuit.

Any trouble in the system can be spotted by making a series of tests with a long connecting wire. In Figure 9-25, the connecting wire, N, is fastened to one lead and to a tester post. The other post is touched in succession to connections E, F, G, H, and C. The bad reading will show up whenever the difficulty is inside the circuit being tested. As an example, if normal readings are shown at E and F, but an abnormal one at G, the trouble is in number 3 cap or its wiring.

After the blasting circuit tests properly, the leading wire B is reconnected. An additional test is then made at the power end of the leading wires.

Warning. Warning must be given of intention to blast. The type of warning may be determined by either law or custom. For large blasts, particularly in pits employing numerous men and machines, blasting should be done at specified times, as at twelve and at quitting time, and should be preceded by definite and well understood signals, such as horns, sirens, whistles, or yelling, long enough in advance to notify everyone and give them time to prepare.

A usual blast signal is a call of "Fire" or "Fire in the hole," repeated two or three times at intervals of ten to thirty seconds. Signals should be arranged by which men detailed to watch entrances to the area can stop the blast if necessary.

It is the responsibility of the blasting crew to make sure that all personnel is out of the way, machines are protected, and that no visitors or trespassers are where they can get hurt.

The area, and particularly any roads or paths leading into it, should be marked with warning signs. If any public roads are within the danger area, traffic should be stopped at a safe distance.

Firing. During the signaling, the wires are connected to the blasting machine or switch, or if a battery is used, one wire is connected to a post. To fire, the blasting machine handle is slammed to the bottom, or the switch is closed.

There is a wide divergence of opinion as to what constitutes a safe distance from which to fire a blast. Some experienced men will take shelter behind a nearby rock or tree, whereas others consider 500 feet a bare minimum. No one should stand in front of a face, at any distance.

Proper barricading may be as safe as distance and more convenient. Full protection requires some sort of roof or overhang. A very safe spot is in the tucked-in bucket of a big dipper shovel which is turned away from the blast. The shovel itself may be protected by wood lagging on the rear of the cab.

The return to the blast should be slow for several reasons. The fumes, which dissipate in a few minutes in the open, are toxic and may cause severe headaches and nausea. If more than one hole has been shot, one of them may fire late. Rocks are occasionally thrown so high that they take a long time returning. Rocks or debris may be lodged precariously in trees.

SPECIAL EXPLOSIVES

Military explosives, of which the most widely known is TNT (trinitrotoluene) are stable and difficult to detonate. They are seldom used in commercial blasting.

Some compounds now used for blasting avoid the hazards ordinarily associated with explosives so completely that they are called blasting agents.

Ammonium nitrate (nitrocarbonitrate) is an industrial chemical and fertilizer that can be made to explode, but is so inert under all ordinary conditions that the In-

terstate Commerce Commission allows it to be shipped without the standard precautions required for explosives.

It cannot be detonated by blasting caps, Primacord, or impact of bullets or steel weights. It does not cause headache.

Explosive manufacturers advise that they have no record of any accidental explosion ever originating in it. However, the cruder industrial form figured in the disastrous Texas City explosion in 1947.

For blasting use, the best known form is Nitramon (du Pont) but it can now be obtained from most explosives manufacturers.

In Nitramon, the powdered chemical is packed in lacquered, rust-resistant steel cans. Standard sizes are 24 inches high with diameters ranging from 4½ to 9 inches.

There is also a large borehole size, 16 x 11 inches. Cans 2½ inches in diameter, with threads that permit them to be assembled in strings, are supplied for seismic prospecting.

The charge is sealed into the can at the factory, and is never removed during handling or loading.

Special primers are made of similar cylindrical cans packed with two grades of amatol, a compound of TNT and ammonium nitrate. One grade is cap-sensitive to a limited extent; the other, packed in the ends, is less sensitive and has sufficient strength to detonate adjoining Nitramon cans.

The primer is initiated by detonating fuse looped through a triple tunnel on the side of the case. In loading a deep borehole two are used, the lower one having two or three cartridges beneath it.

The cans are lowered into the hole individually by a loop on the top end, and a hook that automatically disengages when the line slacks at the bottom. For deep work it is convenient to run the line over a tripod pulley and equip it with a snubbing device.

These cartridges are not dropped because they might cut the Primacord. Also, the chemical is water-soluble, and a puncture in a wet hole might destroy its effectiveness.

Although the detonating fuse is in contact with the whole charge, except for the two or three bottom pieces, it is only effective on the primers.

Nitramon cans will set each other off by concussion at distances of only 8 to 12 inches in open air, and over a somewhat longer but undetermined range in a borehole. Small interruptions in the column from falls of gravel or small stones will not stop the explosion, but a rock of sufficient size to plug the hole might.

Since the containers and the detonating fuse are both waterproof, and danger of accidental explosion is practically nil, holes can be loaded as soon as drilled, even if it will be days or months before they are to be shot.

The above ground part of the fuse must of course be carefully protected, and a booster cap used on it if it has become wet.

If a cartridge or a primer sticks part way down a hole, it can be cut out with a churn drill using plenty of water. Unexploded cans are considered entirely safe to load out of the muck pile by machinery.

This blasting agent is at its best in large well organized jobs where explosives are used in such quantities that ordinary types offer a considerable hazard and handling problem, where its slightly lower cost is an important factor, and where crews can be trained to take full advantage of its special features.

It has practically entirely replaced dynamite in the Mesabi mines, and in many other large operations. It is the preferred material for use in coyote holes.

At present it is less used in smaller scale work, and where holes are excessively ragged and caving.

There are special blasting agents for seismic prospecting at sea, for blasting

burning coal in stripping work, and waterproof, highly insensitive free running pellet form blasting agents.

Liquid Oxygen Explosives. Liquid oxygen high explosives, sometimes known by the abbreviation L.O.X., are composed of finely powdered carbon, usually a special grade of lampblack, and liquid oxygen. When in prime condition, they are somewhat more powerful than TNT or 60% gelatin dynamite, pound for pound.

They are used only in open pit operations, and never in coal or in rock containing any carbon or oil. Their use is practical only near a preparation plant.

Liquid oxygen has a temperature of $-300°$ F., and for this purpose is transported and stored in special vacuum insulated tanks, vented so that no pressure can be built up.

Cartridges are made up of very pure lampblack. One type is 21 inches long and is made in several diameters. The smallest contains 2 pounds of lampblack and 7 of liquid oxygen, and the largest about three times that amount.

The dry cartridges are packed into an insulated "soaking box" that is placed on a scale and liquid oxygen added through a flexible metal hose until the correct weight is reached. The boxes are then delivered to the blasting area, and are well enough insulated to hold the cartridges at full strength for about 24 hours.

As soon as the explosive is removed from the box, the oxygen starts to evaporate rapidly, and they must be placed in the hole within an hour to keep full strength.

Standard loading procedures are followed, but work must be done rapidly. Stemming must be loose enough not to plug the hole, as if evaporating oxygen cannot escape freely, it will blow the stemming and some of the cartridges out of the hole.

Shooting is done with electric caps or Primacord. On detonation, a pound of the charge produces 8.4 cubic feet of carbon dioxide (CO_2) gas. If it is not detonated, the oxygen will evaporate harmlessly in about six hours, leaving a cartridge or bag of inert lampblack.

Use of this type of explosive therefore practically eliminates danger from unexploded charges, either in the drill hole or the muck pile. A little patience is all that is required. The materials are not explosive until they are combined, and then will burn violently but not explode unless confined.

However, liquid oxygen creates a severe fire hazard as it evaporates. Air over-rich in oxygen can make smoldering cigarettes burst into flame, and ordinarily inert or slow burning materials to burn violently. This fluid should therefore be kept at least 150 feet from any open flame, smolder, or sparks. It should be kept from contact with oil, grease, and coal dust.

Occasionally, carbon dioxide will collect in low places in dangerous quantities. It can be tested for by holding a lighted match a foot or so above the ground. If the match goes out in still air, personnel should keep out of the area until it clears up. Carbon dioxide is not toxic, but can suffocate by excluding oxygen.

Shaped Charges. A case containing an explosive can be so shaped as to concentrate the power of the explosion in one small area, building up its pressure and power in somewhat the fashion of a water nozzle.

Shaped charges are used in armor-penetrating weapons such as the Bazooka, for tapping open hearth furnaces, cutting deep well linings, demolition and in many other applications. An application of interest to the excavator is that of breaking boulders.

For this purpose, the unit is designed to produce a number of jets that combine just below the boulder surface and rip it apart. Other parts of the explosive force are channeled so that they knock down pieces

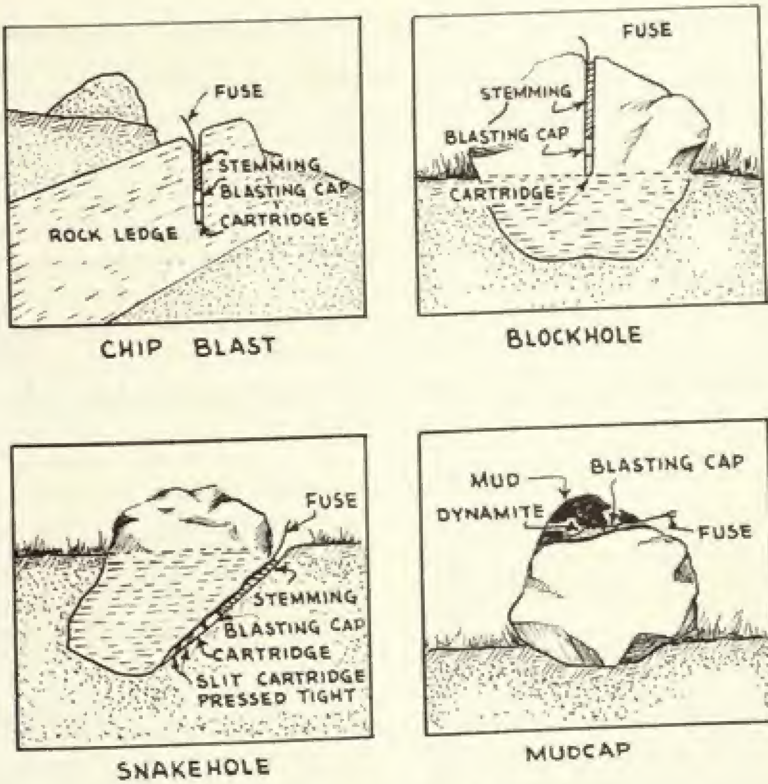


Fig. 9-26A. Spot blasts

of rock that otherwise would fly through the air.

The operation is about as convenient as mudcapping, but less noisy (although more noisy that blockholing) and uses much less explosive. No drilling or covering (except to insure against rock scattering in close quarters) is required.

PRESSURE DEVICES

Coal and some other materials can be successfully blasted by releasing high pressure gases from tubes inserted in drill holes. This gas may be produced by a chemical reaction initiated by electric current, or by heating a charge of highly compressed air or carbon dioxide.

Release pressure is determined by a rupture disc in the discharge end of the tube, at the back of the borehole, which may be set at 10,000 to 22,000 p.s.i. The maximum pressure is about one half that developed by black powder, and one sixth that of permissible explosives, but the action is more sustained. Coarse breakage, with minimum undesirable dust and fines, is obtained.

LIGHT BLASTING

Light blasting, Figure 9-26A, includes loosening up of shallow or small outcrops of rock and breaking boulders. It may constitute the entire job, be done in connection with dirt excavation, or follow heavy blasting which has failed to cut to grade or slope lines, or has left chunks too large to load.

Chip Blasting. Shallow rock outcrops are most conveniently broken up by drilling and blasting. Unless the rock breaks readily along planes more or less parallel with the surface desired, it will be necessary either to drill much deeper than grade or to space the holes closely. It is often good practice to blast each row before drilling the next.

DIAMETER OF BOULDER IN FEET	APPROXIMATE NUMBER OF CARTRIDGES, 1¼ x 8" — IN AVERAGE HARD STONE — REQUIRED FOR:		
	Mudcapping	Snakeholing	Blockholing
1 ½	2	1	¼
2	3	1	¼
3	4	1 ½	½
4	7	4	¾
5	12	6	1

Fig. 9-26B. Charges for boulder blasting

Loading may be light, or very heavy, but in general it is necessary to use more powder per yard of solid rock than in heavier work.

Laminated or jointed formations may be shaken apart by light charges.

Fragments may be thrown long distances, and mats used to confine them are more subject to damage than with deeper blasts.

The amount and direction of throw can often be controlled to a large extent by drilling and loading procedures. A vertical hole causes scattering in all directions. A sloped hole tends to leave the lower slope in place and to throw the upper one away from it. Throw is reduced by increasing the number of holes, reducing the charges, or drilling deeper than required by the breakage line. These two last place the powder deeper where more of its power is applied to breaking and less to scattering.

When breaking must be done exactly to a line, holes are drilled closely along the line and a variable number left without charges.

Blockholing. Boulders and oversize pieces of blasted rock may be broken by drilling a hole slightly more than halfway through, and exploding a small charge of dynamite in the hole.

Fragments may be thrown long distances, so that protection should be provided for the blaster and other personnel. High velocity explosive, or large charges, will produce finest fragmentation.

Chip blasting may be called blockholing also.

An alternative to blockholing is to drill the rock and split it with a three piece wedge set called plug and feathers. The feathers are placed in the hole and the plug driven between them by a hand or air hammer.

A crane and steel ball (skullcracker) is effective at reducing brittle rock.

Mudcapping. Ledges may be chipped and boulders broken by mudcapping instead of drilling. Heavy charges of dynamite are laid on the surface of the rock, primed, and covered with a few inches of mud. The explosion acts as a giant hammer blow and should split or crush the stone.

Knowledge of the grain and jointing of rock is important in successful mudcapping. The charge is placed in the same place which, in handbreaking, would be hit with a hammer or opened with a wedge. In general, hammer-like crushing is most effective on loose boulders, and splitting on ledges.

It is a common error to suppose that the force of black powder is chiefly exerted upward, and that of dynamite downward. In each case the explosion acts equally in all directions, but when it acts slowly it can

find and follow paths of least resistance, where the quicker acting dynamites deliver such a rapid blow that they will crush objects under them, even when not confined. However, a study of the table in Figure 9-26B, showing quantities of dynamite used for blockholing and mudcapping, will show the waste involved in open explosions.

The mud pack over the charge is usually two to six inches thick. It serves to confine the explosion slightly, increasing the force exerted on the rock and reducing noise and air-borne concussion. Mud is much more effective than dry or damp dirt. It should be free of stones or pebbles that would fly long distances.

Charges can be fired on bare rock but are less efficient and noiser.

Mudcapping is wasteful of powder, excessively noisy, and less certain in effect than drill hole blasting. However, it causes less rock scatter than other methods of shallow blasting, and does not require the presence of a compressor.

Snakeholing. Boulders are most readily broken if they are lying on the surface of the ground. If partly buried, the earth or other rock around them provide a support and cushion that may prevent or reduce the breakage.

Embedded boulders may resist machinery which can handle them readily once they are loosened up.

Snakeholing consists of making a hole beside or under a boulder, and firing a charge sufficient to roll it out of the ground, and preferably to break it also. Any further breakage required can then be accomplished by mudcapping.

Snakeholing is more laborious than mudcapping, but is more economical of powder and is much less noisy.

DAMAGE

One of the contractor's problems in connection with blasting is the possibility of real or imaginary damage being done to structures in the vicinity.

An explosive, if properly used, will expend most of its energy in shattering the rock immediately around it. The remaining energy will set up waves or vibrations in the ground, and sound and concussion in the air.

Noise. The noise of an explosion may cause most or all of the neighborhood difficulties. Mudcaps, shallow blasts, overloaded holes, fractured rock, and other conditions that allow the explosion to break out into open air before expending its energies, are productive of complaints all out of proportion to the amount of explosive used.

In the first place, the noise attracts attention to the fact that blasting is going on. It causes the householder to concentrate on trying to feel the jar or shake of the blast, to look for cracks in plaster, and to speculate about other damages that might be done. In many cases, the sound of the blasting will annoy sensitive people so that they will invent or exaggerate physical effects. The contractor or quarry operator's first rule is therefore to blast as quietly as he can in any area where there is a possibility of complaint.

This means a first rule of NO MUDCAPPING. This technique is not only wasteful of explosive, but a sure way to lose the good will of the neighborhood and of the insurance adjuster.

Boulders and oversize blast fragments should be drilled before blasting. The noise is tremendously reduced, and it will usually be found that the saving on explosive and the better fragmentation obtained will more than outweigh the cost of the drilling. When there are only a few pieces, the nuisance of clearing the pit for blasting may be avoided by plug-and-feather splitting. In brittle rock, a crane with a skull-cracker steel ball may be the most economical solution.

In primary blasting, the noise, and par-

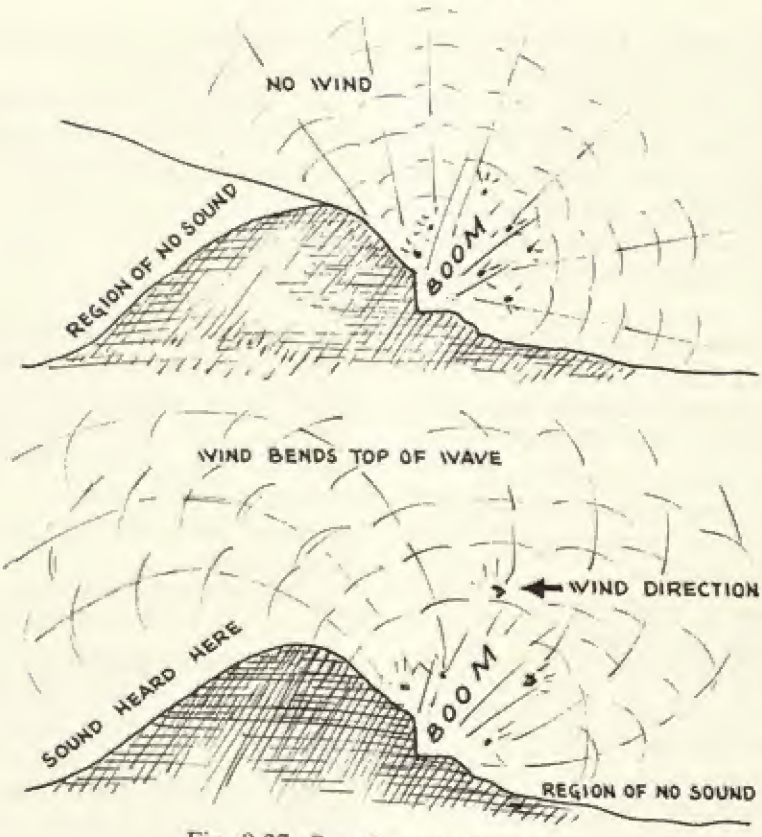


Fig. 9-27. Sound travel from blast

ticularly the shock quality of the noise, can be reduced by use of short period delays. Their more important effect on ground vibration will be discussed later.

Long period delays are productive of complaints. They divide up a shot so that the amount of explosive detonated at one time is greatly reduced, but one explosion frequently uncovers the next in the series, making it very noisy.

If a solid rock blast is a good one, the sound should be dull or muffled. Even a good blaster cannot always get this effect, however. If the face is fractured in places, lighter loading or greater burden should prevent noisy breakout. But this may cause poor fragmentation, with greatly increased need for secondary blasting. About the only general rule here is that the blaster should consider avoidance of noise one of his important objectives.

This anti-noise advice is particularly applicable to quarries and open pit mines that are within earshot of residences. The contractor moves from job to job, his blasting may be only one of many nuisances associated with an improvement, he may be finished and gone before people complain seriously. But the pit operator is tied down to one location for many years, and upon exhaustion of the material in which he is working, will probably wish to move to a similar deposit in the same area. Cities and villages are acquiring an increasing power to regulate industrial activity, by means of zoning and nuisance regulations, so that the reputation the pit has acquired over a period of years may actually determine whether it can move, expand, or even stay in operation.

Sound travels rather slowly. Its distribution is affected by winds, as shown in Fig-

ure 9-27, by reflection from hills, clouds, or atmospheric layers, and by temperature and humidity.

Concussion. Air borne concussion is responsible for a large share of the damage in bombing, and in accidental detonation of explosives, but is rarely a factor of importance in blast damage. It consists of one or more waves of highly compressed air moving outward from the explosion.

Sufficient explosive to cause concussion more than a few feet away should not be used in mudcapping. Even very heavy blasts in solid rock cause little or no concussion if they are laid out and loaded properly.

Any damage caused by concussion is usually obvious. Glass breakage in closed windows at right angles to the path of the waves is the most common result. In the absence of extensive glass breakage, it is very doubtful that any other parts of a structure could be damaged.

When blasting must be done very close to a few buildings of small or moderate value, the question may arise whether the shots should be kept small enough to avoid damage, or whether it would be economical to blast more freely and repair resulting damage. If the latter, the inconvenience to owners or users of the building is a factor in the amount of compensation.

If a building is to be endangered by blasting, windows should be opened or removed, particularly those on the facing and far sides of the house. Store windows may be braced as a routine precaution. Careful check should be made of the condition of plaster and masonry, so that claims need not be paid on preexisting defects.

Rock Throw. Unexpected damage may be done by rock or other material thrown through the air by blasts. In general, shallow blasts, overloaded holes, shots in rock with irregular resistance, and blockholed boulders give the most trouble in proportion to the amount of powder used.

Thrown objects may cause injury or death, and their control is therefore of first importance. Property damage may or may not be severe, but at least claims filed on this ground are usually sincere.

Danger of damage from rock throw may be reduced by increasing the number of holes so that smaller charges may be used, by sloping holes to throw rock away from danger points; by reducing the quantity or strength of powder, and handling any resulting oversize fragments by blockholing under mats or by the use of larger machinery.

Covered Blasts. Throw can be closely controlled by working downward, using small blasts and covering them with mats or chained logs. If the cover is large and heavy in proportion of the strength of the explosion, it will prevent any scattering of fragments. If the charge is heavy enough to lift the cover, it will move somewhat less than the average distance of throw to be expected from an uncovered blast, and fragments with higher than usual velocity will be held in.

It is important that the cover extend several feet beyond the area being shot, particularly if the charge is heavy enough to lift the mat, as fragments might escape under its edges.

When a power shovel is used to remove the shot rock, it is advantageous to use a woven steel mat as it is easily handled with chains, and provides a quicker and more secure cover than logs. The mat is lowered over the holes, or dragged in such a manner that it will not damage the wiring and cause misfires.

Logs are used when no mat is available, or when there is no machinery on the job which can handle one. They should be long enough to overlap the blast at both sides, and light enough to allow the crew to carry them by hand. Two chains should be laid on the ground first, the logs piled, and the chains fastened over them, preferably by

wired square knots.

Chaining is important, as unfastened logs may be thrown farther than rocks.

Neither mats nor logs should be laid directly over mudcaps as they are liable to be thrown long distances, and severely damaged as well.

Blasting mats should be used wherever there is the slightest possibility of fragments reaching people or property. Even a scattering of sand or fine pebbles on their property will make people nervous and resentful, and is an indication that loading should be reduced or technique changed to a safer one.

Ground Waves. The vibration or wave motion set up in rock and soil by a blast constitutes the principal source of both actual and imagined damage to buildings. There are a number of varieties of waves, traveling both deep underground and along the surface. The latter are of primary importance to the blaster and to his neighbors.

The study and description of the movement of particles of earth or rock in an earth wave from a blast is a highly technical subject. There are push waves, that momentarily increase the density of the ground, in the same manner as the concussion wave acts on the air.

Particles are also shaken from side to side (shake or shear waves) and moved elliptically as well. These waves all start off together at a blast, but have different speeds, so they tend to spread out with distance.

On the surface, the ground is forced into waves similar in shape to those caused by wind on water, except that their height is in thousandths of an inch, and the distance from crest to crest is between 100 and 1000 feet. Waves of these dimensions cannot be seen, but they may be felt in intensities as small as 1/100 of that required to do damage.

A diagram of the spreading of ground waves outward from a blast is shown in Figure 9-28. The amplitude (height) of the waves is greatly exaggerated.

It takes a really huge wave of this type, such as might be found in a major earthquake close to its source, to damage any material by shifting its particles. The trouble in structures arises when the foundation moves or changes shape with the earth in which it is embedded, but the inertia of the rest of the building causes it to try to stay in its original place, with resulting stresses set up between foundation and upper structure. The effect is similar to that caused by a heavy wind that pushes and slightly deforms the house, but cannot affect the foundation, and its effect on the structure is seldom more serious.

Surface earth waves in soil ordinarily have a frequency of from 4 to 20 cycles a second. 10 cycles are used as a standard in calculating blast results. The body waves traveling deep underground may have a frequency between 20 and 90 in rock, and travel between 8000 and 26,000 feet a second.

Loose soil moves further (makes a bigger wave) than rock, but it also absorbs and damps out the wave in a shorter distance. The wave height or amplitude, and therefore the possibility of damage, is about 10 times greater in normal overburden 50 feet or less in depth, than in rock. Very deep overburden may shake 30 times as much as rock.

Displacement. The Bureau of Mines has conducted extensive investigations into the effect of earthborne waves on buildings. It is interesting to note that they were forced to resort to machine-induced vibration, as they were unable to find any quarry or tunnel job that produced sufficient jarring in its vicinity to make investigation possible.

The finding is that displacements between 100 and 250 thousandths of an inch (.100 to .250) were usually required to

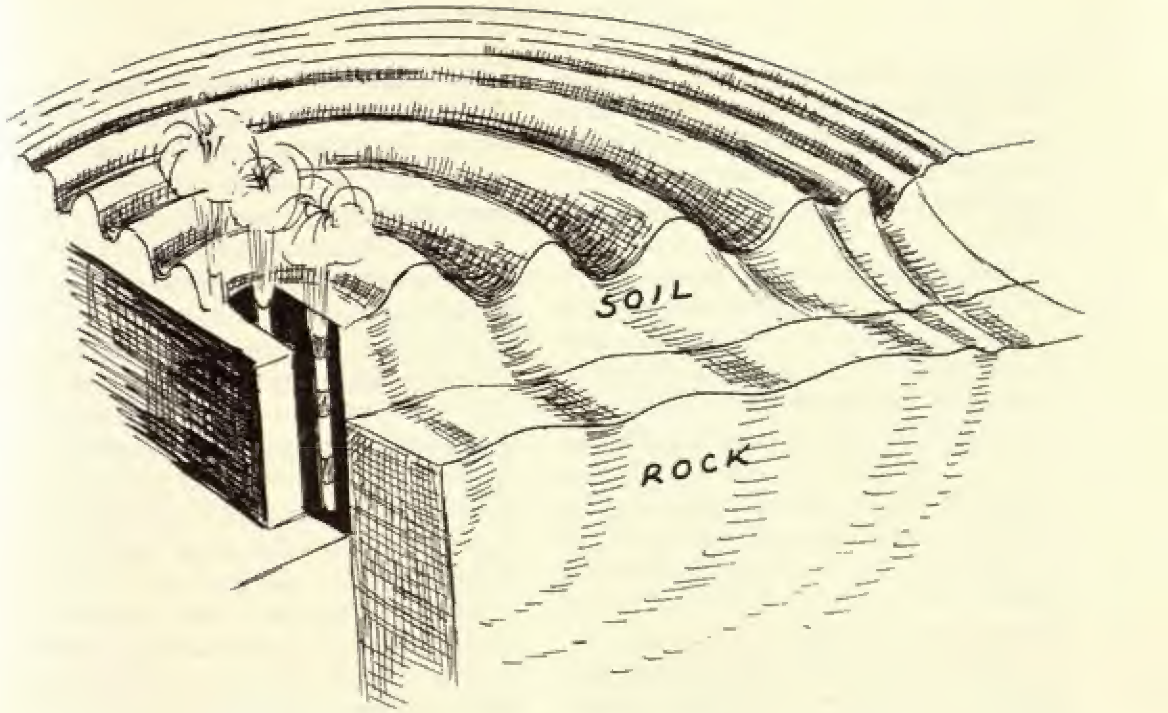


Fig. 9-28. Ground waves

crack or loosen plaster. Occasionally minor cracks were caused by motion of .050. In tests in buildings in the neighborhood of commercial blasting, many of them where complaints had originated, they found vibration to be only .01 to .001 of an inch. These observations were taken at a cycle frequency of 10.

As a result of these tests, the Bureau set up as a safe standard the keeping of blasting vibrations below .050 and the assumption is made that any apparent damage arising from less displacement has other causes.

Energy Ratio. Insurance companies have conducted tests that also included the part played by acceleration of earth movement in building damage. Acceleration is the rate at which a particle changes from a state of rest to the maximum motion imparted by the wave, and since inertia and resulting lag in motion of parts of a structure are the chief source of damage, this acceleration has great importance.

They use a term, Energy Ratio, abbreviated E.R., that is obtained by dividing the square of the acceleration by the square of the frequency of the waves. When E.R. is 3, old buildings that have been pre-stressed by uneven settlement or warping may show slight damage, but sound buildings will be unaffected. At 6, there is a strong probability of damage to residential structures. An E.R. of 3 corresponds very closely to the displacement of .050 inches displacement used by the Bureau of Mines, so the two separate approaches lead to the same result. However, there are serious discrepancies between these somewhat theoretical conclusions, and damages found near actual operations.

Reasons for Complaints.* Studies indicate that much greater vibrations are produced in house structures by slamming doors, running, and often by street traffic, than by even severe blasting. It would ap-

* The material in this and two following sections has been rewritten to include findings from further research leading to conclusions differing from those originally presented.

pear that at ordinary distances the ground and air vibrations set up by heavy blasts are so weak as to be incapable of affecting any structure. Yet complaints and claims for damage pour in on every blasting job. Why?

There are a number of reasons. One is that the ability of rock, soil, and water to transmit vibration varies much more than is indicated by the relatively superficial testing that has been done.

Bulletin 442, U.S. Government Printing Office, 1942, gives a table of vibration amplitude to be expected from various weights of explosives at distances from 100 to 6000 feet. This is frequently used as a guide to safe practice by contractors, with the approval of insurance inspectors.

It would appear from this table that 600 pounds of explosive would not produce sufficient ground waves to damage a house on average overburden 100 feet away. (!!). But there are records of high five figure awards paid for damages done to a village two miles away from an underwater blast of this size, indicating a difference of over 10,000 per cent between theory and fact.

Contractors frequently blast much more heavily than is indicated by their records and statements, particularly when a job gets behind schedule. Mistakes in loading can occur. Variation in the strength and quality of explosives can be a factor.

Most of the checking of blast damage to date has been done by representatives of mining and insurance interests who are more interested in disproving it than in impartial study. Some of the instruments used for measurement leave much to be desired.

There are also psychological reasons for exaggeration of blast damage. Bomb damage received very extensive publicity during the last war and made people over conscious of the dangers of explosives. There is also fear and resentment of the unusual, that makes blast vibration appear more significant than that from a truck.

Still another factor is coincidence. Residences, and plastered buildings generally show cracks and changes in shape progressively throughout their life. Each crack must have a time of appearance. There is no reason why a crack should not appear at about the same time as a blast, even if there is no cause and effect relationship.

Many people are so unobservant that they can live in a house with cracked plaster and sagging beams for years, not noticing until the rumble or jar of an explosion makes them look for possible damage. Cracks and defects then appear to be a direct effect.

Pre-stressing. One of the principle defenses advanced by defendants in blasting damage suits is criticism of the condition of the structure before the blast. If it is in a condition of stress due to unequal settlement, warping or shrinking of timbers, or overloading, it will change in shape and its plaster will crack.

If a blast vibration is within "safe" limits, an over-stressed condition may cause cracking from the blast. The theory is that if the blast had not been set off, the same cracks might have developed shortly from natural causes.

In general, the poorer the quality of construction, the greater the probability that stresses will develop, plaster crack, and mis-alignment occur. But this is not always so.

The Bureau of Mines has prepared a list of 40 reasons for cracking of wall and ceiling plaster as a result of defects in construction. These are of interest not only in respect to blast damage, but as warnings of mistakes or economies to avoid when building. They are:

1. Building a house on a fill.
2. Failure to make the footings wide enough.

3. Failure to carry the footings below the frost line.
4. Width of footings not made proportional to the loads they carry.
5. The posts in the basement not provided with separate footings.
6. Failure to provide a base raised above the basement floor line for the setting of wooden posts.
7. Not enough cement used in the concrete.
8. Dirty sand or gravel used in the concrete.
9. Failure to protect beams and sills from rotting through dampness.
10. Setting floor joists one end on masonry and other end on wood.
11. Wooden beams used to support masonry over openings.
12. Mortar, plaster, or concrete work allowed to freeze before setting.
13. Braces omitted in wooden walls.
14. Sheathing omitted in wooden walls (excepting in "black-plastered" construction).
15. Drainage water from roof not carried away from foundations.
16. Floor joists too light.
17. Floor joists not bridged.
18. Supporting posts too small.
19. Cross beams too light.
20. Subflooring omitted.
21. Wooden walls not framed so as to equalize shrinkage.
22. Poor materials used in plaster.
23. Plaster applied too thinly.
24. Lath placed too closely together.
25. Lath run behind studs at corners.
26. Metal reinforcement omitted in plaster at corners.
27. Metal reinforcement omitted where wooden walls join masonry.
28. Metal lath omitted on wide expanses of ceiling.
29. Plaster applied directly on masonry.
30. Plaster applied on lath that is too dry.
31. Too much cement in the stucco.
32. Stucco not kept wet until set.
33. Subsoil drainage not carried away from walls.
34. First coat of plaster not properly keyed to backing.
35. Floor joists placed too far apart.
36. Wood beams spanned too long between posts.
37. Failure to use double joists under unsupported partitions.
38. Too few nails used.
39. Rafters too light or too far apart.
40. Failure to erect trusses over wide wooden openings.

The pre-stress argument is unpleasantly reminiscent of the whitewash given the Donora smog by a group of doctors. They said in effect that it was nothing to fuss about, as only people with a previous history of respiratory disease had died.

It would be unjust to allow reckless blasters to evade payment of damages on these grounds, or to make property owners go without recompense because their building standards fall short of those set up by the Bureau of Mines. However, blasters should not be compelled to subsidize substandard construction. It is likely that most cases where pre-stressing is actually proved should be subject to compromise settlements.

Water Supply. Blasting sometimes causes springs and even deep wells to go dry. The vibration causes underground movements that may close water passages or open new ones. However, explosives are probably responsible for only a fraction of the difficulties for which they are blamed.

Underground water circulation is under constant change. Old seepage veins become plugged with mineral deposits, new ones are opened by solution and erosion. Changes in rainfall pattern, in conversion

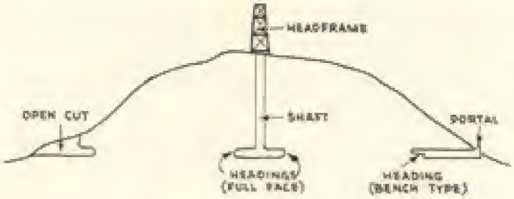


Fig. 9-29A. Tunnel layout

of forest land to farms, or back again, may alter the quantity and location of underground water over a wide area. Over-pumping will lower the water table.

A new well may tap into an underground reservoir of limited size, which once pumped out will not refill. Such a well may show a very high yield on its first test, but decline markedly after long use, when it comes to depend on circulating water only.

Keeping Out of Trouble. Under all ordinary circumstances, blasting should be kept light enough not to damage buildings. The job should be figured on a basis of conservative blasting, and the work done the same way.

Short period delays are a real friend to the man who wants heavy blasts, but is surrounded by structures. Up to 70 percent of the charge of an instantaneous blast can be used with EACH of ten or twelve short delay periods, without increasing the vibration. Or to look at it another way, the same loading can be used as for an instantaneous shot, and 10 periods used to cut the damage potential by four-fifths.

Even with ultra-conservative procedures, inspections should be made of nearby buildings before blasting. If property is valuable, vibration-testing devices will be supplied by the insurance company or by a blasting consultant to measure the disturbance caused. Such instruments should be used to check the next blast in any building or area from which complaints are received.

As detailed before, noise should be kept to a minimum. If there are few people in the area, it should be possible to notify them before blasts, so that they will not feel it necessary to be tense all day waiting for an explosion. Another method, applicable to heavily populated areas also, is to set a definite time or times each day for shooting, and stick to it.

If a claim is made and is justified it should of course be paid. But if it is clearly unjustified, it probably should not be paid even if apparently too small to be worth arguing about. One paid claim is likely to bring in a dozen or a hundred others, and the contractor might find himself replastering and decorating a whole town before he knew what hit him. Payment of any claim makes any other much harder to defend in front of a jury.

Of course, a contractor should protect himself with insurance, and usually does. But in the long run the premiums he pays are based on what the company pays out for damages, so their interests are identical.

DIGGING UNDERGROUND

TUNNEL WORK

Tunnels are underground passageways of any size, and may be natural (as in limestone caverns) or made by animals or men. Those discussed in this section are man made. They serve a variety of purposes, including mining, water supply and drainage, laying sewer and other pipes, railroad and vehicular shortcuts or water crossings, and air raid protection.

Rock tunnels are driven through solid material that usually requires blasting and may support itself permanently, or at least long enough to allow setting up of bracing after digging out a short section. Soft ground tunnels involve digging or pushing aside soil, and the roof (called the crown) and the walls may require support before removing the soil. Mixed-face involve going through both types of ground, either together or in different sections.

Men have driven tunnels since prehistoric times. They usually worked in rock, because the difficulty of digging it was more than compensated by its ability to hold itself up. Cutting was done with hand tools, or by heating the face with wood fires, then throwing cold water or cold water and vinegar on it to cause sections to crack off.

The vinegar technique, with little or no ventilation, must have been really rough on the slaves who did the work. A rough approximation of the atmosphere might be obtained by building a good blaze in a fireplace, shutting off the chimney damper, then putting out the fire with vinegar.

Layout and Problems. The methods used to drive a tunnel vary tremendously with the nature and water content of the material to be penetrated, depth and size required, surface conditions along the route, time allowed, and background of the men doing the job. There is space in this section to indicate only a few of the problems most often encountered, and some standard procedures used in solving them. For a more detailed discussion, the reader is referred to "Practical Tunnel Driving" by Richardson and Mayo, McGraw-Hill Book Company, 1941 and to "Rock Tunneling with Steel Supports" by Proctor, White and Terzogh, Commercial Shearing and Stamping Co., 1946.

"Famous Subways and Tunnels of the World" by Edward and Muriel White, Random House 1953, is an excellent account of the history and methods of tunnel driving for laymen, both children and adults.

The diagrams in Figures 9-29A and B show the layout of a simple tunnel job, and the names for some of its parts. If it is driven more or less horizontally into a hillside, the opening is called the portal. The working face, where the digging is done, is the heading. Vertical access tunnels descending from the surface to the main tunnel level are known as shafts.

In the tunnel itself, the floor is the invert, and the roof is the crown. The spring line is the meeting of the vertical side wall with the curve of the roof arch. A supporting shelf cut at this line is the hitch. A small pioneer or accessory tunnel is called a drift. Standard cross sections are rectangular, round, and horseshoe.

There are a great many special problems connected with even a simple tunnel project. To the open-cut man, one of the most impressive is lack of space. Many tunnels have been driven with cross sections as small as 4 x 4 feet—not even big enough to stand in. Twenty to thirty foot diameter tunnels are big, yet they provide a floor width that would be considered skimpy for a haul road on top.

Equipment to be managed at and near a tunnel heading may include a drill jumbo (a movable frame almost as big as the tunnel, carrying a battery of drills), a machine for loading muck (the below-ground name for spoil) and rail cars or rubber-tired trucks to remove it; the same or other cars or trucks to bring drill steel, bits, explosives and other supplies to the heading, a locomotive to push and pull cars, and a switching or passing device to permit hauling units to get past each other, although there is often room for only a single width of track or roadway.

There will be high pressure air pipes to supply the drills, and often large low pressure ducts for ventilation. Overhead wires or ground cables carry electricity for light, power, and blasting juice. Water under

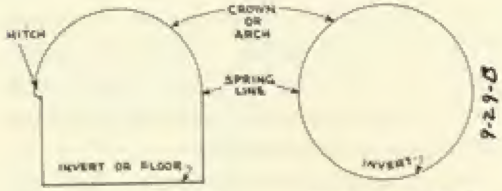


Fig. 9-29B. Tunnel cross sections

pressure may be supplied for wet drilling. A system of drainage, pumping, or both may have to handle tremendous volumes of water.

In addition to the regular equipment there may be need for a diamond drill to make test and grouting holes, grouting equipment to seal off leaks and solidify wet ground, and/or a movable buffer to confine rock throw from blasts.

If the tunnel is to be timbered for support, or lined for support or for permanent use, the crews and materials for this work may follow the digging closely, and in any event will have to work in and over the single entrance way.

If driving is from a shaft, its bottom is another crowded point. Haulage equipment may be lifted to the top to dump, or dump into containers at the bottom. Supplies must be unloaded from the elevator cages and reloaded for hauling to the face. Men coming to work and leaving it, and supervisors and inspectors wait here for transportation to the surface. Pumps, compressors, and even drill and repair shops may be located in skimpy quarters excavated near the shaft.

Sequences are very exacting. The tunnel cycle (the succession of drilling, shooting, and mucking) must keep the largest possible number of men and machines usefully employed, and the time interval from any operation to its repetition should not vary. Whenever possible, two or more operations should be performed simultaneously, as drilling the top of a face while digging the bottom, and installing lining a few feet back at the same time.

When two headings driven from one shaft are close together, one may be drilled while the other is shot and mucked. With increasing distance the advantages of this arrangement are reduced.

Most tunnel crews are the universal type, and perform all operations in the cycle. This saves the contractor from paying a crew waiting time because of a delay in a prior operation.

Speed. Under favorable conditions, tunneling may progress very rapidly. The Owens River Gorge Power Tunnels in the Los Angeles water system were driven as fast as 104 feet in a day, and 2442 feet in the best 31 day period.

On a start-to-finish basis, the fastest tunnel on record is the six mile Carlton drainage tunnel in Cripple Creek, Colorado, which was completed in under 2 years. Both of these were about ten feet in diameter, and unlined.

The 25 foot diameter Kemano Tunnel in British Columbia set a record in 1952 of 274 feet in 6 days.

The longest tunnel in the world is the 85-mile Delaware Aqueduct in the New York City water system. This was driven from 26 shafts, with no single section longer than 5 miles. The longest tunnel driven from just two headings is the 13-mile Alvah B. Adams in Colorado.

Gold mines at Kimberley, South Africa, hold the depth record at 9000 feet. These tunnels must be air conditioned, as otherwise the heat would make it impossible to work in them.

The 12-mile Simplon tunnel in the Alps is 7000 feet beneath the surface at one point. Temperatures up to 131 degrees were encountered in drilling it.

The record for maximum excavation in a single tunnel project is now being made in twin power tunnels at Niagara Falls in Canada. These are each 51 feet in diameter and 5½ miles long, and together may require over 5,000,000 yards of excavation. See Figure 9-36.

There is such constant improvement in tunnel driving techniques, and increase in confidence to undertake bigger projects, that some or all of these records may have been surpassed by the time this book is in print.

Plant. The plant at a tunnel may include

the tower, hoist, and hopper; compressors, low pressure ventilation system, water pumps, electric transformers or generators, change rooms with showers and lockers, provision for emergency treatment of injuries, a blacksmith, forging, and bit dressing shop; welding and repair equipment, and telephone or radio communication systems.

Compressors are usually at the surface. They are usually of the two-stage type, and have an aftercooler as well as an intercooler, to avoid transporting any heat of compression into the heading, which is often too hot already.

Alternating current is used. When possible, it is purchased from a utility. It is usually stepped down to 220 or 110 volts at the entrance, but on some jobs is taken in at several thousand volts, in armored parkway three-wire cable. Dry transformers (oil filled ones are a fire hazard underground) are set about a thousand feet back from the faces, and advanced in long jumps as progress warrants. This system avoids the power loss and voltage drop associated with long distance transmission of low voltage current.

There may be three electric circuits in the tunnel, a 220 or 440 volt for power, a 110 volt for light, and a high voltage line for firing explosives. Some operators standardize on 220 for both lighting and power. 220 bulbs are sometimes a nuisance to get in this country, but they have the advantage of being useless in an ordinary lighting circuit, so they are seldom pilfered.

There may also be a two inch line to take water to wet drills. This water may have to be picked up outside the tunnel if the groundwater is heavily mineralized.

Surveying. Tunnel sections meet each other far from their portals or shafts, sometimes after curves, with uncanny precision. Differences usually vary between a small fraction of an inch up to several inches. These are too small to be noticed on the walls, but are measured at the surveyed center line (axis).

An underground direction is obtained by establishing a base line at the surface, running close to the line of the tunnel. This is very carefully done, and it is marked at frequent intervals by permanent monuments, with exact points pricked into copper bolts embedded in concrete.

Two plumb bobs weighing twenty to thirty pounds each are suspended close to the bottom of the shaft by piano wire from the surface. They are as far apart as shaft width permits. Vibration and tendency to swing may be dampened by hanging them in pails of water. Very careful observations are taken of the wires at the surface, relative to the proposed tunnel center line. Direction is identical with that of the same wires at the bottom.

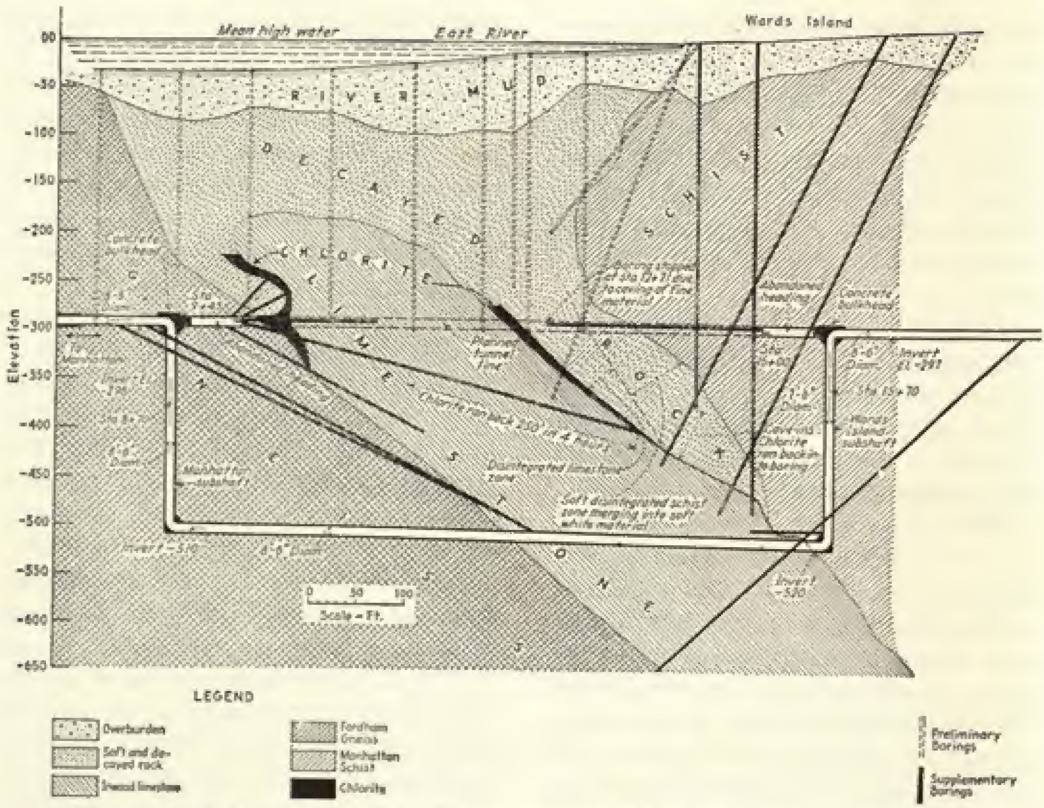
Careful observations are taken of the bottom part of wires, using a very accurate instrument and special sighting devices. Readings are taken over and over again, and the results averaged. The tunnel line is then established in the correct direction, by reference to surface readings.

This work must be done at a time when men and equipment are not working, as ventilating currents and vibration can disturb the wires.

The line is extended through the tunnel on spads (markers) driven into plugged holes in the roof. These are also used for grade checking.

Exploration. Tunnels are seldom driven blind. Preliminary drilling is done along the route to determine the type of rock, the amount of water to be expected, and the danger of mud slides. Test holes are drilled from the surface, usually with diamond drills that can bring up cores for inspection.

Diamond drilling may also be done from the heading, where dangerous conditions are expected. This precaution has often revealed the presence of such quantities of water or unstable soil ahead, that disaster



Extensive core drilling on Wards Island sewer tunnel under the East River, New York, showed the way to get under a bad fault that stopped driving on original upper level tunnel. Preliminary borings failed to reveal true conditions.

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Fig. 9-30. Underground exploration and tunnel detour

might have resulted had it been broken into by a full-face blast.

Figure 9-30 shows extensive core drilling that was done for a sewer tunnel under the East River, New York City, in order to find a way to avoid a dangerous seam of decayed rock.

Dangers. Underground work is naturally very dangerous, and it is greatly to the credit of tunnel men and labor departments that there are so few accidents.

The most evident danger is that of collapse. Most soils and many rock formations will slump rather quickly into any hole cut under them. In any given material, this tendency increases markedly with depth. Below 500 feet even apparently firm rock may creep, and break off slabs with explosive violence. There is always danger of loose pieces falling.

Caving and breaking off are combatted with compressed air, timbers, steel and concrete linings, and holding bolts.

If the soil will not stand at all without support, bracing must be installed ahead of the digging; or the heading protected by a movable shield.

Water, with or without accompanying soil, may break into a tunnel in such volume as to flood it completely within minutes. Escape of men may be difficult, machinery is apt to be abandoned, and an expensive and tedious job of sealing off the water and pumping out the tunnel is often required before work can be resumed.

Fire must be carefully guarded against,

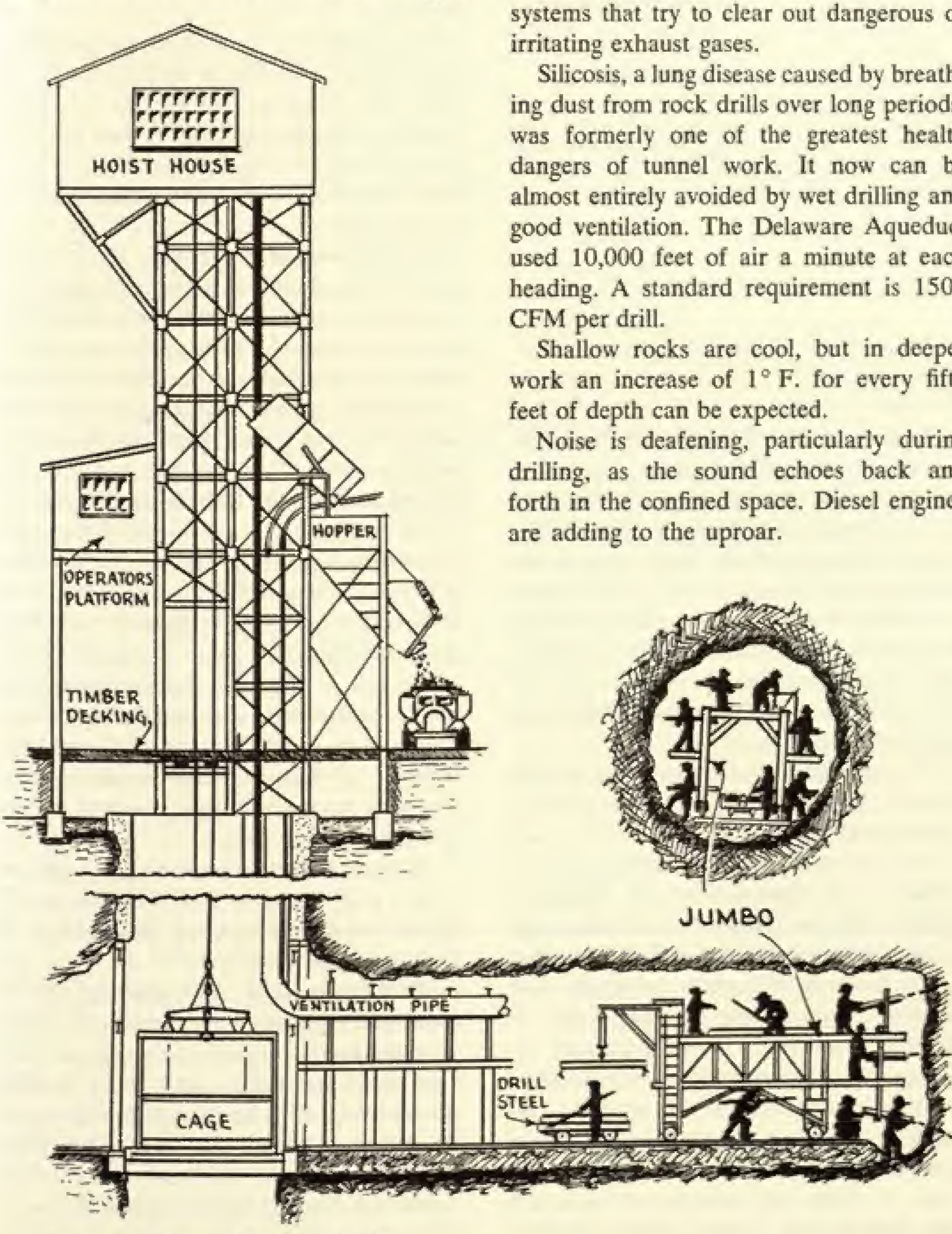
particularly on jobs using compressed air and/or timbers.

Air conditions are difficult to keep healthy. Drills produce rock dust, and most air powered machines have foul, oil-charged exhausts. Explosives produce fumes. Some clay and rock formations give off unpleasant or poisonous vapors. The increasing use of internal combustion engines underground makes tremendous demands on ventilation systems that try to clear out dangerous or irritating exhaust gases.

Silicosis, a lung disease caused by breathing dust from rock drills over long periods, was formerly one of the greatest health dangers of tunnel work. It now can be almost entirely avoided by wet drilling and good ventilation. The Delaware Aqueduct used 10,000 feet of air a minute at each heading. A standard requirement is 1500 CFM per drill.

Shallow rocks are cool, but in deeper work an increase of 1° F. for every fifty feet of depth can be expected.

Noise is deafening, particularly during drilling, as the sound echoes back and forth in the confined space. Diesel engines are adding to the uproar.



Courtesy of Delaware Water Supply News

Fig. 9-31. Shaft and heading equipment

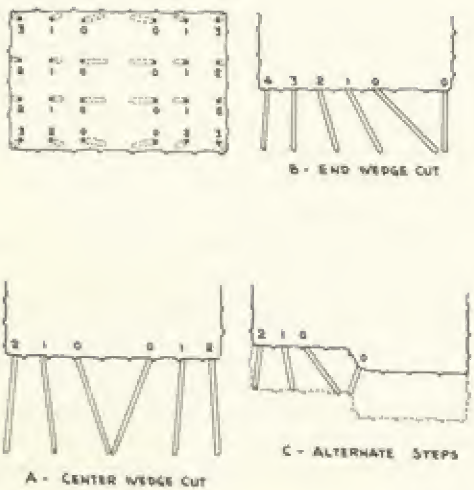


Fig. 9-32. Wedge drilling in shaft

SHAFTS

Shafts—vertical passages between the tunnel and the ground surface over it—are required for the majority of tunnel jobs. They are sometimes the only access. Even when there are portals, shafts shorten the time required to do the work, as each makes it possible to work on two extra headings. In addition, underground hauling is a headache, and runs should be kept as short as practical. Some shafts are part of the permanent tunnel project.

The advantages of shafts must be balanced against the considerable expense of sinking and equipping them.

Shaft location may be chosen to keep depth to a minimum, as in the troughs of valleys over the tunnel; to take advantage of an easily worked or stable formation; or on the basis of surface conditions such as cheap land, nearby dumping areas, or distance from areas where noise and appearance might be considered objectionable.

Size. Shaft size is highly variable, depending largely on the volume of material it must handle and the size of objects that must be lifted and lowered. A minimum size, about 11 by 13 feet inside the lining, accommodates a single hoist and supply elevator and a ladderway. The ladderway includes a ladder, electric and high pressure air lines, water pump discharge pipe, and ventilator ducts, all of which must be protected from swinging loads or falling chunks.

The headframe is a tower of prefabricated steel, as in Figure 9-31, or may be built with timbers. This carries the hoist sheaves, dumping mechanism, and the discharge chute or hopper. The hoist engine and winch is ordinarily in a separate structure nearby.

Soil Excavation. Digging is started with a clamshell, which can dig soft soil unaided, and remove hard soil and rock after they have been loosened. One or two signalmen direct the operator's movements, as he cannot see the bottom, and any wrong move with the heavy bucket might be disastrous to the workers. The clamshell is ordinarily not used below a 25 foot depth.

The next stage may be to replace the digging bucket with a light bucket or container that is lowered to the floor, and loaded by hand or by equipment suited to the cramped work space. The container is raised out of the shaft by the hoist line, swung to the side, and dumped by a trip device or by hand. This may be used to a depth of 100 feet, or a direct transition may be made from the digging bucket to use of the headframe hoist.

A special small clamshell may operate from a platform close to the bottom, loading the containers that are lifted past it to the top by the main hoist.

Blasting. In shaft rock blasting all the holes are tight—that is, there is no open face to permit sideward throw of the rock—so that close drilling and heavy loading are the rule. It is necessary that the rock be cut back cleanly to the digging lines and important that overbreak be kept to a minimum, because of the high expense of removing muck, and the frequent requirement of filling all spaces outside the lining.

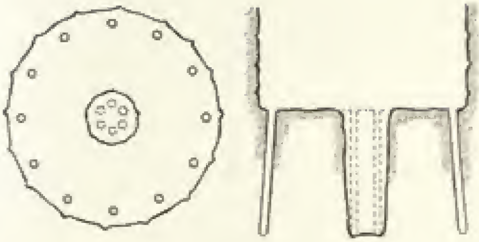


Fig. 9-33. Burn cut

Figure 9-32 shows typical drilling patterns for shaft and tunnel work. A set of two or more converging angle holes (wedge holes) are drilled, and other sets of straight or slightly angled holes next to them, until the rim is reached. The wedge holes are heavily loaded, so that they crush and kick out the rock between them, making an opening into which the rock around can move sideward when the next ring of holes is fired. These in turn make space for the next set. Firing is best done by short period delays.

In (B) the floor is lowered on only one side in each shot. This permits drilling to be resumed on one side while muck is being loaded from the other.

Figure 9-33 shows a burn hole shot, with the center holes parallel instead of angled.

The blast is fired from the top, after all men and equipment are out of the shaft, except that in very deep work some equipment might be merely raised far enough to be out of immediate danger.

After the explosion the bottom will be full of fumes, which would take a long time to dissipate naturally. These may be blown out by lowering the tool air lines with the ends open, or extending low pressure ventilating ducts to the bottom. (These have to be dismantled or pulled back a considerable distance to avoid damage from the blast.) A suction line (foul air duct) is more effective at cleaning the air than a blow or pressure line, as the fumes tend to settle.

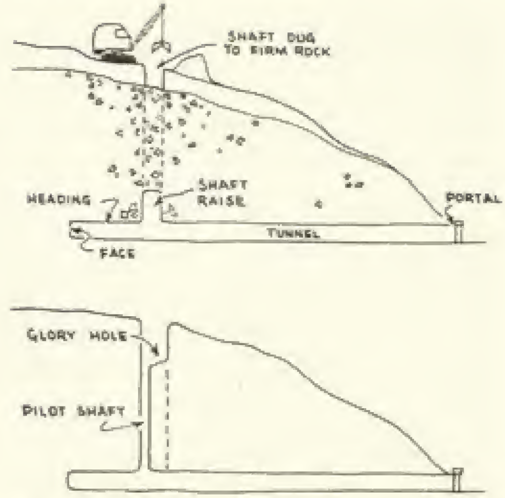


Fig. 9-34. Raise and glory hole shaft excavation

Some shafts are large enough to provide space to load the muck by machinery, but in many of them it is tossed, rolled, or hand shoveled into buckets or skips, that are removed by the hoist when filled. The best fragmentation for this type of loading is usually one-man stone, that is, pieces that one man can handle conveniently.

Drilling can be resumed as soon as part of the bottom is cleared. Six or seven foot steels giving a five foot penetration are often used, but longer or shorter ones may be better in particular circumstances. Hand and wagon drills are standard, although special jumbos have given good results.

Working Up. When a large shaft is required as part of the finished job, but is not needed for the early tunnel work, it may be more economically cut from below. With this method the blasted rock falls to the tunnel floor, and is removed through the portal.

The glory hole method is to sink a small pilot shaft to the tunnel, then to dig the large shaft from above, blasting or pushing the muck into the small shaft so that it will fall to the tunnel. See Figure 9-34.

Shaft Lining. In soft ground the shaft is protected from caving by setting sheeting

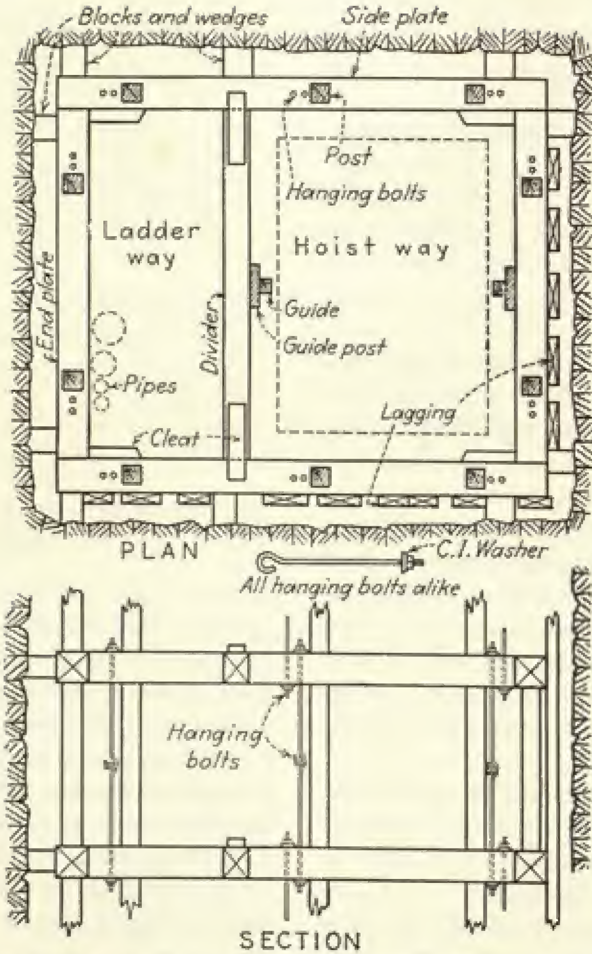


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Fig. 9-35. Timbering for small shafts

planks or sheet piling, held by whalers, in much the same way described earlier for ditches and cellars. The whalers are interlocked at the corners to hold each other in position, and additional divider beams may be run across between the ladderway and the hoist way. See Figure 9-35.

If the soft soil is too deep to be held by sheeting driven from the top, successive layers can be driven from inside the shaft, inside the upper ones. If the sheeting is driven with an outward batter, shaft size will be preserved. If driven straight, the inside diameter of the shaft will decrease, so that the top would have to be oversize to allow it to be full size at the bottom.

Shaft lining or timbering is required for the hoist and to a less extent for the utilities even when the soil or rock is self-supporting. When not needed for wall support, timbering may follow twenty or more feet behind the digging, to avoid interference with the work, and damage to the lower section in blasts.

The lining must be supported vertically to prevent it from slipping down. Each new set is fastened by hanging bolts to that above, and every hundred feet or so horizontal notches or shelves are cut into the walls to provide fresh support.

Fig. 9-36. Tunneling with big equipment

Timbered shafts are usually rectangular, while metal or concrete linings call for circular cross section. Steel ribs are made up, curved to the proper arc, and divided into two or three pieces that are lowered endways and then supported by hanging bolts until fastened into a full circle. The actual lining or lagging may be sheet piling or similar material, or the ribs may be built as liner plates, with curved flanges which butt against those above and below to make a continuous sheet.

A continuous lining or lagging is used in soil that might squeeze between ribs or timbers, or in rock that scales or breaks off so that falling pieces would endanger workmen. Unlagged walls may often be kept intact by spraying with concrete or a bituminous mixture.

Drainage. Most shafts are wet. If there is only a little water it can be bailed into the bucket and hoisted with the muck. More often it is removed by a pump with a discharge line reaching to the surface or, if the height is great, to one or more pumps that help push the water out of the shaft. All pumps used in deep shaft work should be able to develop very high discharge pressures, so that a good lift can be obtained between boosters.

If water conditions are severe, the area may be predrained by sinking 4 to 12 inch holes with churn drills, and pumping from them. Depth is too great for ordinary well point work from the surface, but in flowing ground well points may be sunk from the shaft bottom or sides, and the water rehandled by the regular pumps.

A deep wet shaft should have gutters and sumps at intervals, to catch water running down the sides. Pumping to the top from intermediate points is more efficient than allowing it to get down to the bottom, and raising it from there.

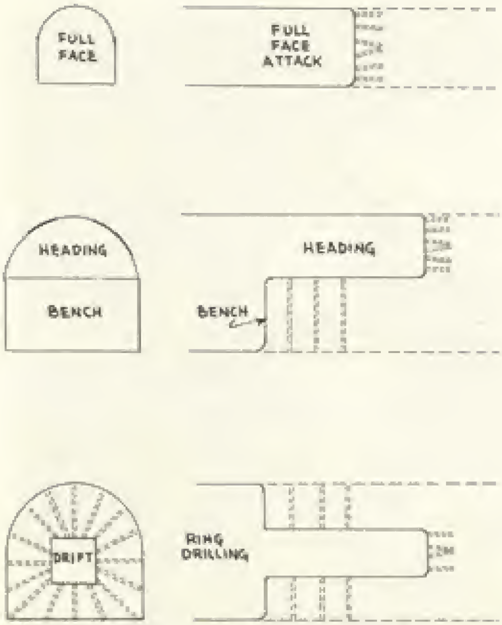


Fig. 9-37. Tunnel headings

HEADINGS

A heading is a digging face and its work area.

When the shaft has reached the level of the proposed tunnel floor, two headings are started, one in each direction along the line of the tunnel. In addition, the foot of the shaft may be greatly expanded for storage and maneuver space, and one or more rooms may be built to house compressors, pumps, and other plant equipment.

At first only a single set of tunnel driving equipment may be used, as there will not be space enough for two, and greatest efficiency will be obtained by drilling at one face while mucking at the other. Room for two sets will be made very quickly, but alternate work is sometimes continued until the distance between headings is great, or sometimes for the whole job.

Drilling patterns may be similar to those described for shafts—wedge or burn holes, and successive rings breaking into the crushed-out area. The whole face is usually drilled and blasted in one operation (full-face attack), but a small tunnel (drift) may be drilled full face, blasted, and cleaned out, then enlarged by radial drilling; or the top may be kept ahead of the bottom (bench-and-heading method). See Figures 9-36 and 9-37.

Pilot Tunnel. Shafts may be partly or wholly replaced by a small pilot tunnel, driven parallel and close to the main tunnel. Crosscuts are driven from this to the main tunnel wherever new headings are to be started. The main tunnel is opened up with a center drift, and enlargement started after it is cut through enough so that both tunnels can be used for traffic.

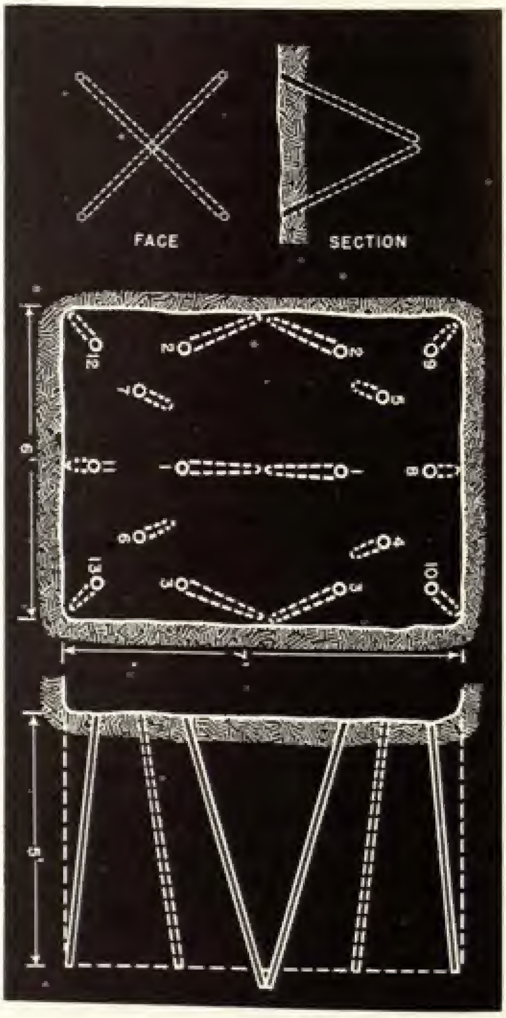


Fig. 9-38. Small tunnel drilling pattern

The extra tunnel may be used for ventilation, both during the work and afterward. It permits a great many operations to be performed at the same time, and may save considerable expense in sinking shafts. This method has been used chiefly for long railroad tunnels through mountains where depth was too great for shafts.

Drilling. The standard tool for small tunnel drilling has been the drifter, a medium weight hand drill with a hand or automatic feed, mounted on a vertical column or a horizontal bar of such length that it can be secured between the floor and roof, or between the sides, by screw-jack ends. Because of the weight of the columns, they become impractical for full face work in tunnels of greater cross section than 10 x 10 feet. It is now being replaced by hydraulic boom mountings.

The drifter permits the drill crew to resume work on the top of the face as soon as blast fumes have cleared away, with the drill men standing on the pile of muck until it is dug away. They can drill the bottom after it is cleared.

Larger tunnels were formerly done by the heading-and-bench method. This permits the use of drifters on short columns for the advance, and approximately vertical jackhammer or wagon drilling for the bench. Sometimes the heading is extended far ahead of the bench, and has its own hauling equipment that dumps over the bench face into other cars, or into a pile to be dug away.

Now the standard method is to use a drill carriage (jumbo) on which power feed drills can be mounted so as to reach all parts of the face at correct angle and to correct depth. Each drill usually does several holes. It can be positioned by hand, or by mechanical, air, or hydraulic controls. Such jumbos may be so constructed as to straddle hauling equipment, so that it need not interfere with removal of muck. They may also carry a cherry picker crane to pick up empty cars to switch loaded ones through. They are backed away from the face before each blast.

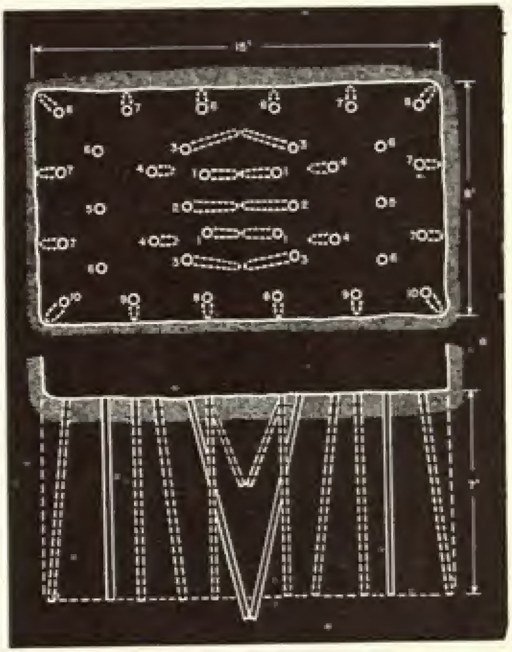


Fig. 9-39. Drilling pattern, large tunnel

On very large tunnels jumbos may be used on both levels of heading-and-bench work.

Usual drilling depth is 10 to 12 feet, but in any case is seldom deeper than two thirds the smallest dimension of the tunnel.

Figures 9-38 and 9-39 show typical full face drilling patterns.

Bits. Recently tunnel drilling has been partly standardized to use steels threaded to carry detachable bits. These may be multi-use types that can be sharpened by grinding, or sharpened and reshaped by hot milling; one-use or throwaway bits that are discarded when dull; and carbide insert bits. In some mines carbide tipped steels are used, and in others the old fashioned steel with the business end forged into a bit is still doing business.

The carbide insert bit has caused a spectacular advance in speed and ease of hard-rock tunneling. Many tunnel men say,

"There is no such thing as hard rock any more." Carbide outwears steel at an average of about a hundred to one, and gives much more rapid hard rock penetration. The time of handling, transporting, and processing bits is reduced from a major to a minor problem.

Loading. Water resistant explosives with good fume characteristics are desirable in underground work. These qualities are found in gelatin dynamites.

When all holes in a face have been drilled, each is blown out with a high pressure air jet to remove loose cuttings and water. Cartridges are slit (unless the explosive is damaged by water and the hole is wet) and tamped firmly with a wooden pole. It is common practice to place the primer after the first cartridge, with the cap pointed toward the collar of the hole.

Stemming may be taken from the drill cuttings. It is most convenient to use if wrapped in paper bags of the same size as the cartridges. If this material is very high in silica its use as stemming might increase the silica in the air enough so that prewrapped blanks supplied by powder manufacturers might be preferred. There are also wood and rubber plugs that are very satisfactory.

It is good practice to place a wad of paper between the explosive and the stemming, so that the powder can be easily and safely located in case of a misfire.

There is danger of premature explosion from stray currents. A common precaution is to take down or "kill" all electric wiring within five hundred feet of the face before starting to load. Safety flashlights, of hand or cap models, or headlights from a battery locomotive can be used. It is sometimes a question whether the poor lighting obtained does not offer as much of a hazard as the electricity would.

Even the complete absence of electricity on the job would not guarantee a tunnel face against currents, as underground water is often highly mineralized and will conduct a charge for long distances. Metallic ores may be excellent conductors.

The precautions described earlier for blasting in the presence of electrical hazards should be followed.

Firing. Any wiring hookup can be used —series, parallel, or parallel series, depending on the preference of the blaster. If 440 volt electricity is available it is preferred for firing, although 220 or even 110 will do. Regular blasting machines are also used, but they should not be kept in the tunnel when not in use, because of possible damage from dampness.

All equipment is moved 500 to 1000 feet back from the face, as rocks caroming off the walls can travel long distances. Compressor pipe can be left fairly close to the blast, but ventilation conduit must be stripped way back.

Move-back requirements may be reduced by a portable metal buffer wheeled into place or set up on the jumbo before the blast.

Checking. It is important that a thorough check be made after the blast for misfires. Tunnel work brings a large number of men into close contact with the heading, and any accidental explosion during mucking or drilling would be disastrous. The best check is inspection by experienced men.

If an unexploded hole is found, and the wires are intact, they can be hooked up and fired. If the wires are missing, the stemming can be washed out by a water jet, and a new primer inserted and fired. Or a parallel hole, about two feet away, can be drilled, loaded, and fired. The muck must be inspected for unexploded cartridges.

MUCKING

Loading. In small tunnels blasted rock may be dug by hand, although the excellent mechanical loaders adapted to work in tight quarters that are now available, and the rising price of labor, are steadily reducing

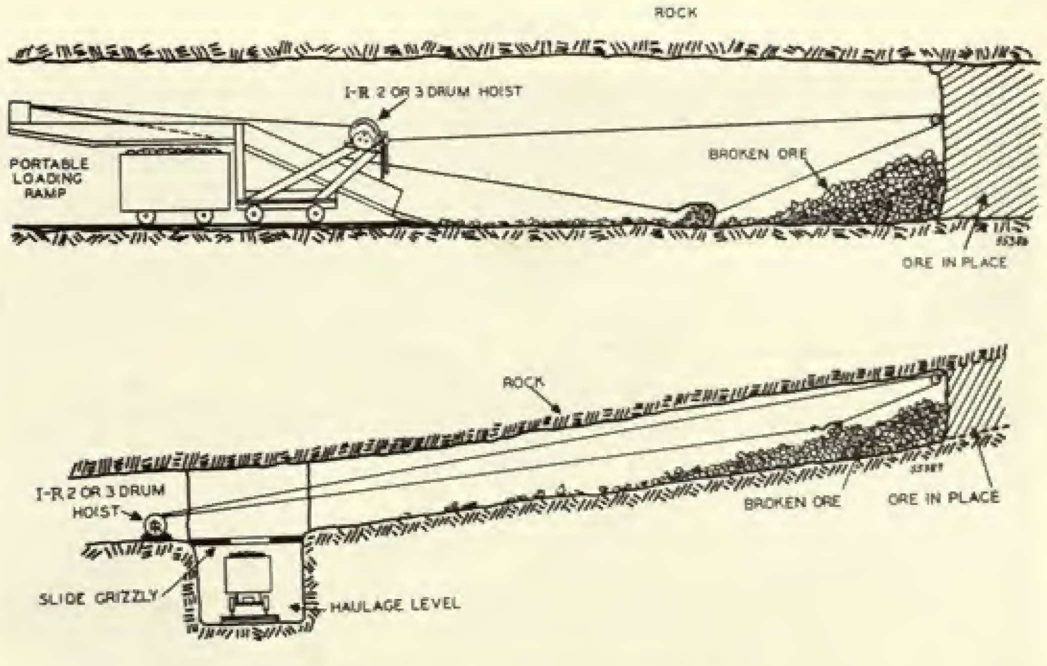


Fig. 9-40. Drag scraper installations

the practice. Output for the loading gang is generally figured at about ½ to ⅔ yards per hour per man, although one man may load up to 2 yards under favorable conditions. The difference lies in work of loosening, handling cars, and other delays.

The swell or "growth" of rock in passing from the solid to the blasted state averages about 50%. In tunnels, mucking is usually calculated in terms of loose yards, in mines in number of tons loaded.

Slick sheets should be used in connection with hand loading. These are thin steel plate, ¼ or $\frac{5}{16}$ inch, in pieces about 4 x 6 feet, with holes punched for convenience in picking up for moving. They are laid to cover the tunnel floor for 10 to 25 feet back from the face before each shot. Large rocks are picked up and thrown into the cars individually, while the finer material is dug by shovels that slide easily along the metal surface.

Mechanical loaders include full revolving shovels with short booms and proportion-

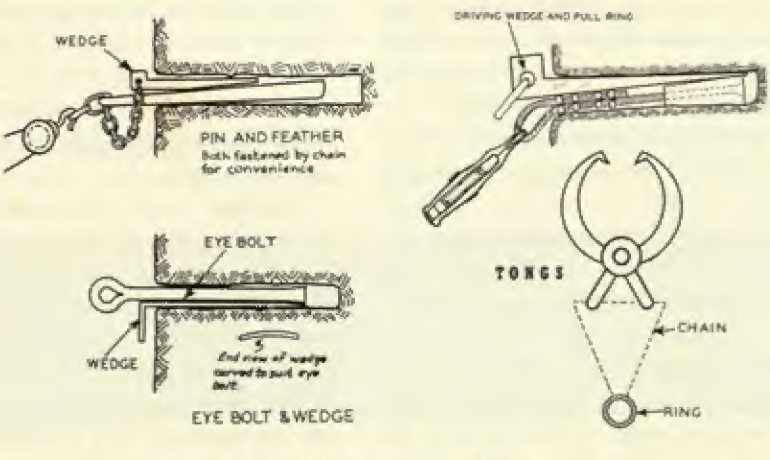


Fig. 9-41. Drag scraper anchors

Fig. 9-42. Diesel-powered mine locomotive

ately larger buckets, that move either on crawlers or rails, and until very recently used only air or electric power. There are also railroad type shovels that use one track and load cars on another beside it, and may have a cherry picker for changing cars on the back.

Special tunnel-mucking machines are available in large variety. Most of them are rail-mounted, although crawlers are gaining in popularity. The bucket can be swung from side to side to reach the full floor area, and is filled by pushing into the pile.

It is then lifted, in some models over the machine to discharge into a car or conveyor belt behind; in others it loads a built-in conveyor that discharges to the rear. In either case, the car may be coupled to the mucker so that it is always in loading position.

Slushers are drag scraper units that usually have a metal slide to support and guide the open-bottom bucket and its load, as in Figure 9-40, top. The slide may be long enough to accommodate several empties in addition to the one being filled.

Another drag scraper method employs a trap fitted with grizzly bars to support the bucket, as in 9-40, bottom. In this case the train comes through at right angles to the scraper slide, and is moved as each car is filled.

The scraper tail block must be anchored on the far side of the digging. If this is the face, a bolt or flexible fitting is usually wedged into a drill hole in it, as in Figure 9-41. If at an intermediate point in the tunnel, it may be attached to a timber by a hook or tongs.

Hauling. Any type of hauling unit may be used in a tunnel, from a wheelbarrow to an off-the-road ten wheeler. It is a matter of tunnel size, speed of driving, ventilation, and preferences of the management.

The traditional system is small muck cars pulled along narrow gauge tracks by electric locomotives. The locomotives can take power from either batteries or high lines,

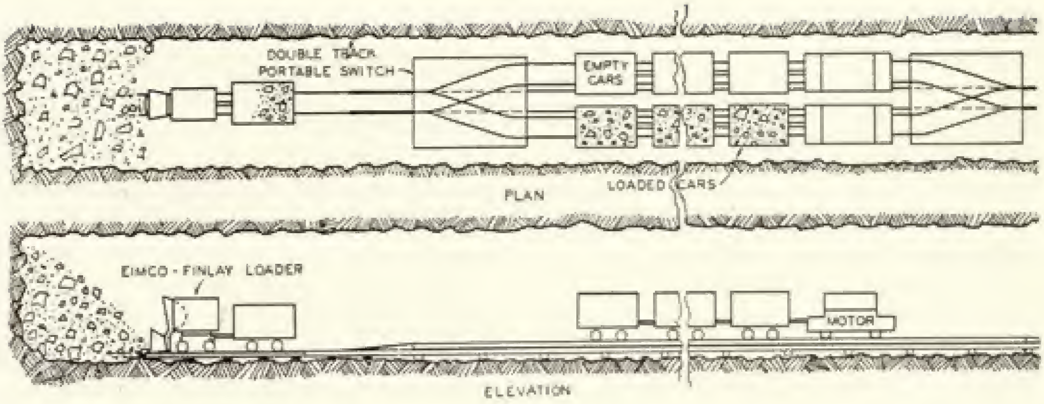


Fig. 9-43. Portable switch

and range in weight from 4 tons up. There is an increasing use of diesel locomotives with exhaust conditioners in well ventilated tunnels. See Figure 9-42.

Cars are usually side dump types, although many special constructions are found. The width is governed by the tunnel and the gauge of the track, and should be small enough to allow passing in the tunnel. Car width is generally about twice the track width.

The capacity of the car may be limited by switching arrangements. If they are pushed by hand, capacity is limited to one or two yards, as heavier cars will need to be pried along the tracks, rather than shoulder-pushed. The car must be low enough to go under the discharge of the mucking machine being used. If hand loaded, it must not be over four feet high.

The loaded muck cars are hauled to the shaft and run into hoisting cages, in which they are lifted to the top, where they are dumped by side tipping. There are also special cars that can be lifted directly, without entering a cage. Or they may be dumped at the bottom into a hoisting skip.

The perpetual problem in tunnel haulage, which becomes more acute as size decreases, is bypassing the empty cars (or trucks) going to the face around the full ones coming away from it. Empty cars may be switched to the side; or if they are small, be lifted or pushed off the track by hand, where there is space for only one track. Larger ones may be handled by a cherry picker. In either case the spotting arrangement shown in Figure 9-43 may be used.

The locomotive pulls a string of empties into the heading and stops to let the cherry picker take up the rearmost car and set it aside. The locomotive then backs far enough so that the car can be replaced on the track in front of it; then pushes that car up the loader. While it is being loaded, it backs so that another car can be picked off.

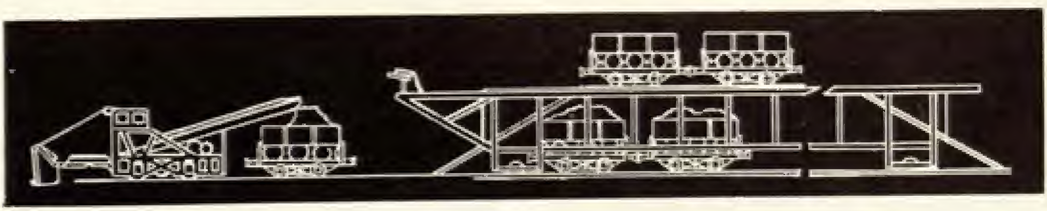


Fig. 9-44. Grasshopper overhead switch

When the car is loaded, the locomotive couples to it and backs past the cherry picker, which places the empty in front of it to be pushed to the face. While it is loaded, the rear empty is again set aside, to be pushed in on the next cycle. When all the cars are filled in this manner, the locomotive pulls them to the shaft.

In a tunnel of sufficient height, a movable framework called a Grasshopper, Figure 9-44, can be used. This allows the empty cars to be moved over the loaded ones, and can be pulled up to the face by the loader.

A conveyor belt may be set up so that a full train of cars can be backed under it, and loaded one by one from the front back.

Conveyor belts can also be set up to haul from the face to the shaft. No switching arrangements are required, but this unit cannot be used readily to bring supplies from the shaft to the face; considerable work is involved in dismantling or protecting it for a blast, and there is constant work adding sections to keep it in touch with the digging.

Diesel-powered trucks are increasing in underground popularity. They carry much bigger loads than mine cars, and if sufficient width is available to make passing possible, they get past each other with fewer complications than rail-mounted carriers. The shuttle types, such as the Dumptor, which are equally comfortable going backward or forward, are often better adapted to the work than those which have to be turned in the tunnel.

The use of internal-combustion engines fouls the air, so that very good ventilation is required.

Exhaust Gas. The exhaust from a gasoline engine contains carbon monoxide, an odorless but poisonous gas that soon makes any closed-in place deadly to life. Amounts of monoxide that are not sufficient to cause unconsciousness or death may temporarily damage judgment and reasoning power, causing an increase in danger of accidents.

Diesel exhaust contains little monoxide, but it is rich in various chemicals that smell badly, are irritating to eyes and throat, and that fog up the air so that visibility is dangerously reduced. This last difficulty is increased by the usually bad lighting in a tunnel.

The danger from gasoline engine exhaust has largely prevented use of this type of power underground. Diesels are finding increasing use in spite of the irritation and danger they cause. Their presence is partly compensated by increasing the ventilation, but conditions do become very bad. They are often made worse by an astonishing lack of care in adjustment of the engines. Diesel trucks sometimes emerge from tunnels belching black smoke, presumably caused by defective or souped-up injectors, that would justify arrest of the driver on an open highway.

Various types of scrubbers using water and chemicals to dissolve and neutralize gases, and secondary catalytic oxidizers that serve also as mufflers, are used to make internal combustion engines acceptable underground. These are described in Chapter 12.

Good ventilation and lots of it is a basic requirement, even when such devices are efficient. The most they can do is reduce the exhaust to carbon dioxide and water. Carbon dioxide is not poisonous or irritating, but in sufficient concentration it has a suffocating effect that can cause impairment of judgment, unconsciousness, and death.

WATER

Ground water is a problem in most tunnels, and may be the principal one in some. Many mining tunnels, some of them miles in length, are made solely to lower the water table. There may be seepage all along the line, adding up to a considerable volume to be drained or more often pumped

away. Gushing springs may be exposed by any blast, or may open up from seepage points well behind the face. Underground lakes or rivers may be encountered that are capable of flooding the work in spite of continuous pumping. Veins of soft water soaked soil may be found in hard rock, that may break into and fill the tunnel.

The first necessity is to have adequate pump capacity. The tendency is to underestimate requirements, largely because pumps and lines are expensive, partly because even careful exploration from the top seldom reveals the full quantity and pressure of water that may be encountered.

If a tunnel runs uphill from a portal, drainage may be by natural flow through a ditch cut along the side. If an upgrade from a shaft, it can be drained to a pump inlet at the shaft foot. This arrangement is easy and inexpensive, but seldom satisfactory, because of repeated blocking of the ditch by rock falls from walls or from hauling equipment, resulting in water running over the floor, making it sloppy and often undermining the track or spoiling the road surface. The ditch also takes up more space than a pipe, and there has not yet been a tunnel with floor space to spare.

The conventional arrangement is to pump all water. A small centrifugal pump, usually air-driven, is kept near the face, and takes from a sump and discharges into a pipe running back toward the portal or shaft. Another sump is provided every 500 to 1500 feet back to collect local water for another centrifugal, usually electric-powered. Each pump may discharge into the sump behind it, which is kept down by another pump, usually of a larger size. Another arrangement is to have all pumps discharge through check valves into a common discharge line. A powerful electric pump of the piston or centrifugal jetting type is installed at the shaft bottom, and as many boosters as are required for the lift installed at intervals in niches in the shaft.

Pipe lines vary from 1½ to 10 inches in diameter.

The pump or pumps at the base of the shaft are sometimes placed in a sealed room, with power and control directly from the shaft top. In other cases the pumps are in the open, but are of the submersible type. These arrangements permit use of the units along with emergency pumps if the tunnel should be flooded.

Grouting. Water inflow can often be checked by grouting. This may be done by drilling deep into the rock in the direction of the supposed source of the water, sealing in pipes with cement, and then pumping in cement and water grout, either straight for seepage or mixed with sawdust or shavings for gushing flow. This may be done in advance of the tunnel driving in very wet areas, by fanning the grout holes out from the face and edges of the heading, as in Figure 9-45.

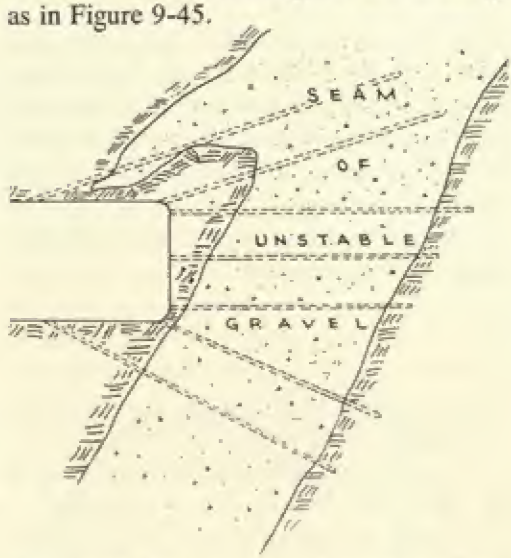


Fig. 9-45. Exploration and grouting holes

Grouting is also done through completed linings, either to check water or to fill in spaces between it and the wall. Grout pipes may be cemented into a concrete lining when it is poured.

Successful grouting of a wet seam sometimes merely diverts the water so that it

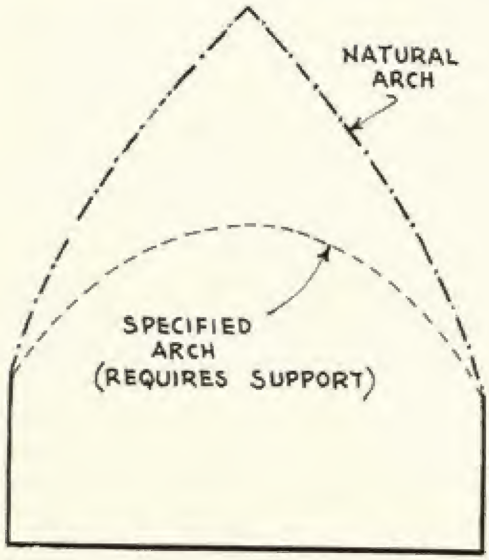


Fig. 9-46. Cutting crown for self-support

enters the tunnel at another point that was previously dry. This also may be grouted, but a point may be reached where the contractor either installs a complete concrete lining, or gives up the effort to seal off and relies on his pumps.

The above-ground uses of grouting were discussed in Chapter 6.

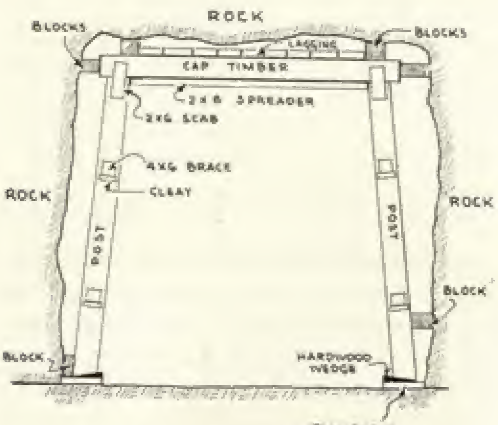


Fig. 9-47. Timber set, small tunnel

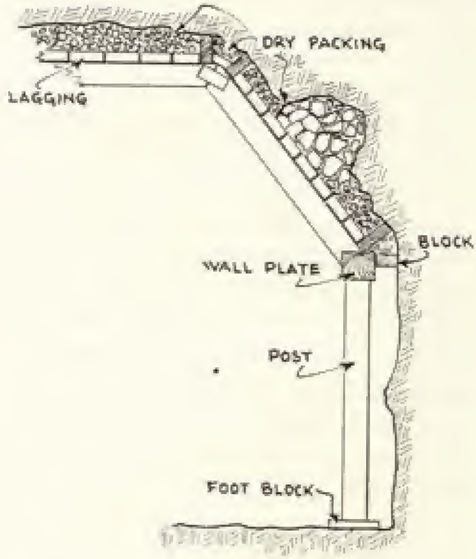


Fig. 9-48. Timber arch on posts

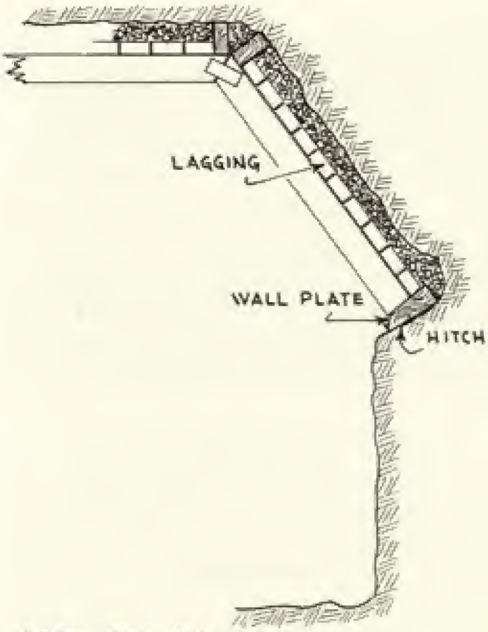
ROCK SUPPORT

Ground pressure in rock tunnels is difficult or impossible to estimate. This problem is dealt with in detail in "Rock Tunneling with Steel Supports." In firm formations there will be little or no pressure until depths over 500 feet are reached.

However there are soft, joined, or laminated formations that will scale off or fall from a flat or moderately curved roof, until a Gothic or pointed arch develops, after which it will be self supporting. If bracing is done only to support the roof, it is a question whether it will not be more economical to cut up to a stable roof line, and avoid placing of supports. See Figure 9-46.

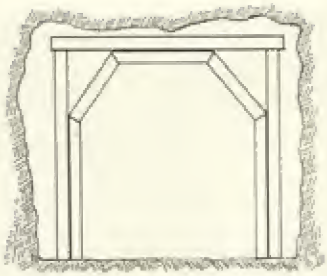
In any roof problem, width is a very important factor, as wide spans will drop pieces or fall in much more readily than narrow ones.

Many rock tunnels are perfectly safe without any bracing. Many others get by without accidents. But very often it is necessary to place supports directly after the digging, or within a few days. Also, the



ARCH SET ON HITCH

Fig. 9-49. Timber arch on hitch



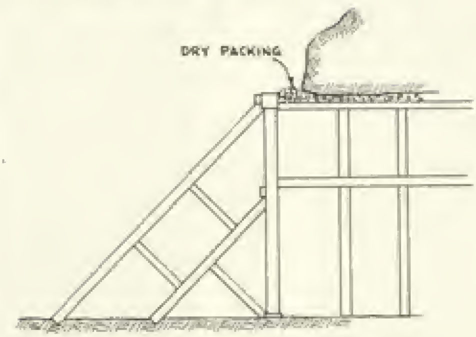


Fig. 9-50. Timber bracing at portal

majority of tunnels outside of mines are more or less permanent in nature, and except in very firm rock, will require lining to prevent deterioration and to reduce or eliminate maintenance.

Support or lining may be wood timber, steel ribs, plates or bolts, or concrete. Concrete is frequently placed inside one of the other types of support.

Timber is the oldest material used, and is found in ancient tunnels. Concrete was used to some extent by the Romans, and has become the standard for permanent installations. Steel liners and roof bolts are quite modern developments, and are rapidly replacing timbering.

Timbering. Figures 9-47 to 9-49 show some designs for timbering. The square-set framing is confined to small tunnels, and various forms of arch construction can be used in quite large ones. The arch may be supported on posts supported in the floor, or rest on a springline shelf (hitch) cut in the sidewalls. Support may vary between these methods with changes in ground, or in shape of the edges.

Posts should be fastened to the wall plate by dowels, lag bolts, or scabs (nailed-on pieces) so that they cannot fall if relieved of weight.

The weight of timbering varies with expected ground pressure. Sometimes it is merely a light roof to catch light rockfalls, at other times a high strength lining designed to resist squeeze from all directions, including the bottom.

Where timbering ends at a portal, or at an enlarged shaft base, it must be securely braced by diagonal beams, as in Figure 9-50, so that any compression developing in the tunnel will not squeeze it out.

Packing. In rock or soil that tends to push in, it is important not to leave any space between the lagging and the wall or roof, as any inward movement will increase the instability of the ground, and may cause it to exert tremendously more pressure than if it had been held in its original position.

An exception is found in swelling or squeezing ground that is allowed a limited space for movement.

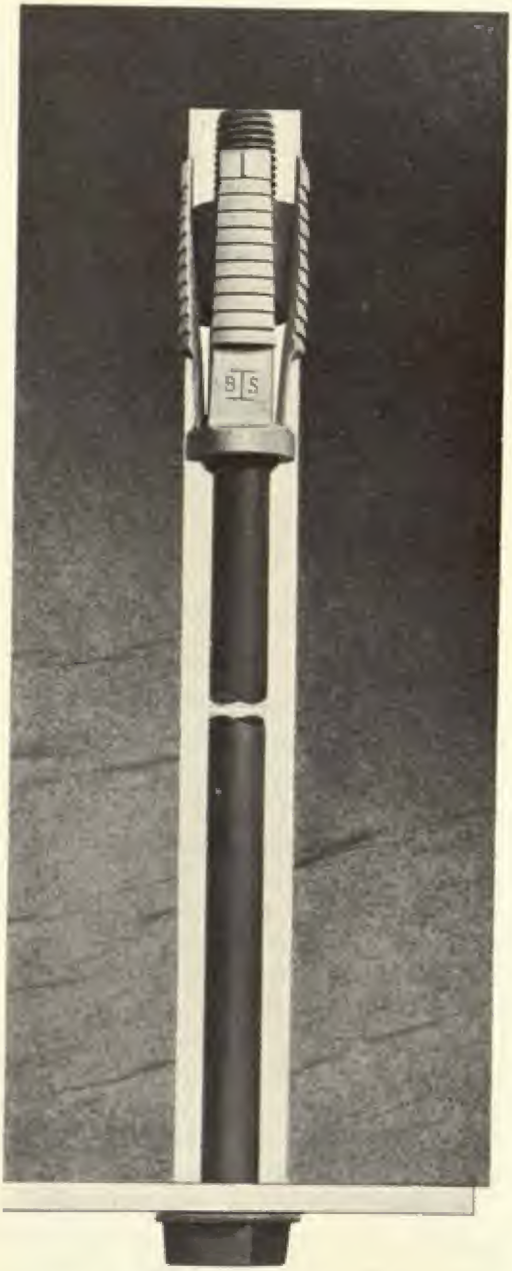


Fig. 9-51. Square head mine roof bolt with shell

Initial movement is prevented by packing the space between the lagging and the rock. The most economical system is to use a dry packing of fine muck, which is shoveled behind the planks as they are placed. At the crown it must be thrown in from the end and securely rammed—a tedious, disagreeable job that is seldom well done.

Large overbreaks may be filled with dry walls built of chunks that can be handled by one man. Packing of scrap wood is good only for temporary service, as it will ultimately decay and leave voids. Timbering for permanent or semi-permanent use should be creosoted, as the wet conditions commonly found are very conducive to decay.

Dry packing may also be done with pea or birds-eye gravel shot into place with pneumatic guns, either through holes in the lagging, or from the end. Its use is more common in soil than in rock.

Lean concrete, with a cement-sand-small stone mix of 1:3:6 or 1:4:8, can be shot into the arch with a pneumatic placing tool. This must be very dry so that it will not leak through cracks between the planks. This is done after the set has been erected and securely blocked, as the fresh concrete may impose very heavy stress.

Lagging is usually set closely (skin tight) in the crown. On the walls it may be widely spaced or lacking, as even if the rock squeezes in, the spans between timbers are too short to allow bulging. Under very heavy conditions, the timbers may be set skin tight, so that lagging is not needed.

If the tunnel is to be concreted, the lagging may be placed inside the timbers, to provide a smoother outer form that saves concrete yardage. The disadvantages are that much more packing is needed and that the fastening is under tension rather than compression, so that heavy pressure may make the lagging pop off the timbers. The effect may be cumulative, as yielding of one fastening increases the strain on the next, so that a considerable length may give way at one time.

Steel Ribs. Steel supports are now standard in tunnel work. They are easier to handle, and allow substantial saving in ex-

Fig. 9-52A. Plates and angle washers

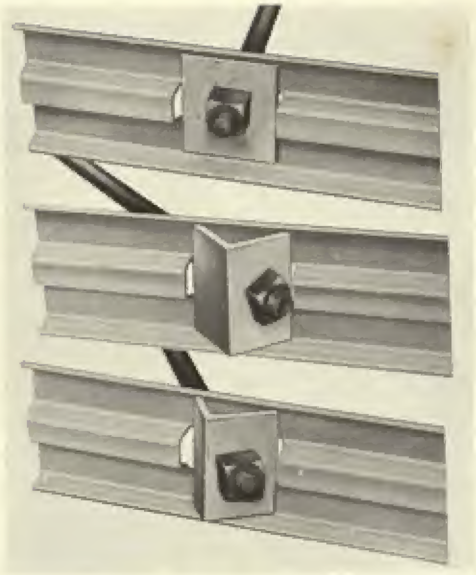


Fig. 9-52B. Mine roof ties, with bolts and washers

cavation. This is because for a given strength, they are only half as thick; and the projections of ribs into a concrete lining are counted as reinforcing. In timber construction, the outside line of the concrete is figured as the inside line of the timbers, and the concrete used to fill out to the lagging is largely figured as waste. On small tunnels the saving in excavation may be 30 per cent and in concrete about 50.

However, steel liners are more vulnerable to blasting damage, and do not give warning of impending collapse under load by groaning, as timbers do.

The steel ribs are made in two pieces, occasionally more. They are brought in endways and set up individually. The lagging may be wood planks or steel liner plates. If the former, the ribs must be well strutted to each other to keep them in line.

As in the case of wood, steel lining may be only a roof or crown support based on shelves at the spring line in the side walls, or a complete tunnel enclosure.

Roof Bolts. It has been found in mining and tunneling operations that unsafe rock will often support itself safely over wide spans if it is reinforced with steel bolts.

In laminated (thin bedded) formations the effect is similar to that obtained in plywood and other layered wood constructions. Several weak and thin layers may be very strong when bonded together. In jointed and fissured rock, the bolts if used properly and in sufficient numbers, restore to the rock the massive strength it had before it separated into blocks and pieces.

Expansion bolts are used, rather similar to those that fasten wood framing to masonry. Figure 9-51 is a ¾″ square headed bolt, obtainable in lengths from 2 to 8 feet. It is threaded into the plug of an expansion shell that fits into a 1⅜ inch diameter hole. Ears on the bolt prevent it from sliding too far into the shell, so that tightening pulls the plug down into the shell, expanding it against the sides of the hole.

Washers or plates of plain, tee-hole, and angle types, and roof ties shown in Figure 9-52, are available for use under the head, to prevent it from crushing into the rock,

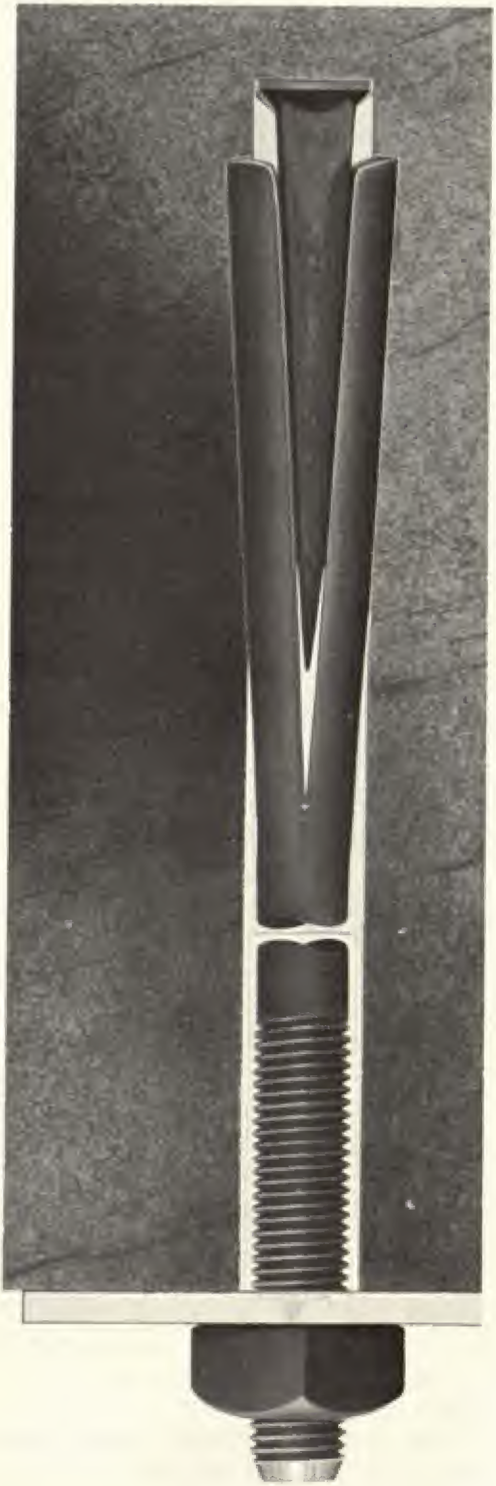


Fig. 9-53. Slotted mine roof bolt

and to spread the pull over a wider bearing area, and to provide support between bolts. The tee-hole type permits passing over the head of the assembled bolt without removing the shell, where the others require separating them, putting the washer on the bolt, and reassembling. The holes in the roof ties are large enough to pass the shell, so that washers are required for each bolt.

This type of bolt does not require an exact-depth hole. Bolt and shell are inserted, and the head tightened with a torque of 150 to 200 foot pounds, usually with an air impact power wrench. This exerts sufficient pressure to bend the roof ties down into any irregularities in the rock surface. The grip of the expansion shell in hard shale, sandstone, or limestone is usually in excess of the 20,000 to 24,000 pound breaking load of the bolt. In medium shale it is said to vary between 14,000 and 22,000 pounds, and in soft wet shale between 6000 and 13,000.

The one inch bolt in Figure 9-53 is intended for use in a 1¼ inch hole, which should be drilled to exact depth. A wedge is inserted in the slot at the unthreaded upper end of the bolt, which is inserted in the hole and driven to refusal with an air hammer. The end is spread by the wedge until it anchors firmly in the hole. A nut is then threaded on to the projecting threads and tightened. Similar washers are used.

If the roof is too low to permit inserting a bolt of the full length required, short bolts and extension pieces can be used.

Bolting requires from one-fifth to one-tenth the steel required for ribs and lagging, and under many conditions is equally strong. In addition, it saves the need of excavating space in which to set the steel structure, and reduces the amount of concrete required for permanent lining.

Elimination of all ribs and timbering makes a tunnel easier to work in, as there are fewer obstructions, and it provides for a smoother flow of ventilating air.

Another important advantage is that the economy of the work causes it to be done on roofs that might be judged to be self supporting if bracing were time consuming and expensive. The bolts can also be installed right up to the face immediately after blasting, so that protection is available to the heading crew. As a result, their use in the rather wide range of conditions where they are applicable results in a marked decrease in roof-fall accidents.

Heavy wire mesh may be used to prevent falling of small fragments in between the bolts. In some instances gunnite is used to minimize air-slacking and spalling.

Rock anchor bolts, which are similar to the slotted mine roof bolts, are used along highway and railroad cuts to prevent rock falls and slides.

Concrete Lining. Installation of concrete lining is construction rather than excavation work (however necessary it may be to the excavation) and will be only briefly considered.

There are two general procedures—soft ground technique, in which it is placed immediately behind the digging, and is necessary to the driving of the tunnel, and hard ground. Under the second heading comes work in rock that is self supporting, and requires lining for permanence, scaling protection, or waterproofing; and unstable soil or rock that is adequately held in place by timber or steel.

The soft ground technique is to follow the heading closely, with some resulting interference between operations. Perhaps the most serious is maintaining a track for muck cars through the pouring operation, and across the freshly laid invert (floor). Steel beam bridges may be used to carry the track in this section.

The invert may be laid about 1½ inches low, protected with planking, and brought up to grade with a top dressing of cement mortar as a finishing operation after the tunnel is complete.

Traveling forms of various types are used. For fast schedules, it is essential to have telescoping forms that can be folded up and moved through other forms supporting more recently poured sections. On other jobs, forms are used that can be collapsed just enough to break away from the concrete surface so as to be moved ahead to the next section. In either case, the forms are carried on carriages, that may move on steel wheels and tracks, or on rubber tires, depending largely on the muck haulage method used.

Breakthroughs. It sometimes happens, in spite of precautions, that there will be a sudden rush of water or mud into the tunnel. This most often occurs at the face immediately after a blast. Sometimes the source is a limited underground pocket which will give no trouble after it once drains off. At other times a stream or large body of water will keep up a continuous flow. If the water is muddy, or the flow is partly or wholly mud, an unstable soil formation has been reached which may give increasing rather than diminishing trouble.

In any case the first step is to seal off the face with a bulkhead (wall) as quickly as possible. Timber, sandbags, or sandbags with timber may be used. Occasionally timber may be backed with concrete.

The bulkhead must not be used as a dam while being built. Pipes should be built into it large enough to take the water flow until the structure is complete. Otherwise water pressure will tend to destroy the bulkhead as it is being erected, and conditions will be very dangerous to personnel. With water discharged through pipes, the structure can be properly and strongly made and keyed into the tunnel rim. The water can then be controlled by valves on the pipes.

The bulkhead should also be fitted with pipes for grouting and concrete placement. After the water has been shut off, grout can be injected into the space between the bulkhead and the break, and will sometimes

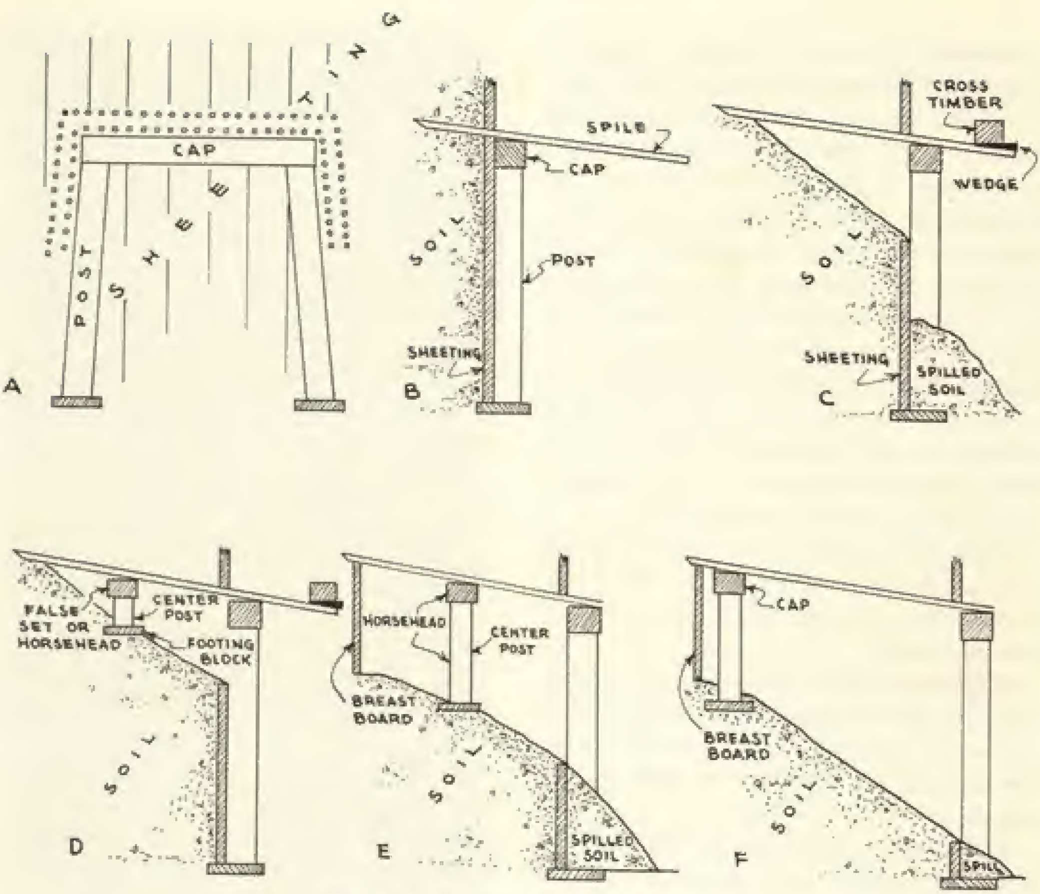


Fig. 9-54. Forepoling soft ground

work back along the water seam and stop or reduce the flow. Grouting may also be done through exploration holes drilled through the bulkhead and into the rock beyond. Over 90,000 bags of cement have been used to control one water pocket.

Further tunneling through such a spot is first in the form of drifts (small tunnels) each of which serves as a base for further grouting, until the ground is consolidated enough to drive the big tunnel.

SOFT GROUND TUNNELING

Soft ground is divided roughly into the following subclasses, description of which is abbreviated from "Practical Tunnel Driving" by Richardson & Mayo, McGraw-Hill 1941:

Running ground: Must be instantly supported. May be dry sand or gravel, quicksand, silts and muds.

Soft ground: Roof must be instantly supported, but walls will stand vertically for a few minutes.

Firm ground: Roof will stay up unsupported for a few minutes, and the side walls and face for an hour.

Self-supporting ground: Will stand unsupported while the entire tunnel is driven a few feet ahead of the timbering.

There are three standard methods of driving through soft ground: forepoling with wood or steel, shield, and compressed air (plenum method). The third may be combined with the other two.

Forepoling. The use of plank forepoles was formerly the standard method of driving a tunnel through soft ground. While this

technique has been largely replaced by steel liner and poling plates, it is still widely used on jobs too small to justify obtaining steel.

In forepoling, the tunnel is protected by timbering, and by breast boards set against the face. Planks are driven through slots cut in the breast board and supported cantilever fashion to make a temporary roof, under which dirt can be dug and permanent supports installed.

Figure 9-54 indicates the terminology of the parts and something of the method.

Starting from a shaft lined with plank sheeting, a bent (cap or roof timber and two post supports) is set and securely braced close to the sheeting. Close set holes are drilled through the sheeting in a double line just above the cap and a single line about 18 inches below it. Double vertical lines are drilled just outside the posts.

A set of light forepoles or spiles are made of 2 x 6 planks five to six feet long, sharpened to a chisel point on one end. A piece of sheeting is knocked out between the lines of drill holes above the cap, and a forepole is rested on the cap and driven through the hole, at an upward slant of about 2 inches per foot, for about half its length. Another bit of sheeting is cut or knocked out, and another forepole driven in the same manner, parallel to and touching the first. This process is repeated until the full width of the cap has been covered.

Spiles are then driven into the sides, flaring out about 2 inches per foot, to a penetration six or eight inches deeper than the roof pieces. These may be driven horizontally, or at an upward slant to keep contact with the roof.

A timber is now placed across the shaft, immediately above the free ends of the roof forepoles, which are then forced downward slightly by driving wedges under the timber. The poles are now supported on the cap and held down tightly by the timber and wedges at the rear, so that the front is supported cantilever fashion.

The sheeting is then broken out from the spiles down to the lower line of holes, and the ground allowed to run into the tunnel until it assumes its natural angle. The resulting slope will normally not extend back to the points of the forepoles, but will end at some intermediate position.

Next a horsehead, or false set, is placed under the poles about two feet beyond the sheeting. This consists of a cross piece under the spiles, and a center post set on a small supporting block in the dirt. The spiles are then driven to their full penetration, substituting the support of the horsehead for that of the cap rear timber.

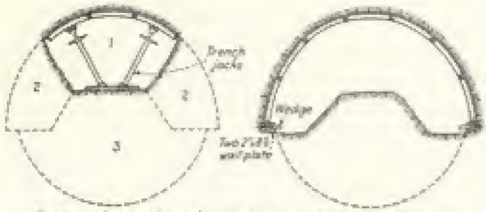
Earth is then raked in until the points of the spiles are almost uncovered. A board the width of the cut and about 18 inches high is set vertically immediately under them. This serves as a breast board to keep more dirt from flowing in, and supports the spiles.

A cap timber is then set to line and grade, and is temporarily supported by a single center post. A "bridge" of 2 x 6 planks is fastened to the top of the cap but separated from it by 4 inch blocks.

The remainder of the side spiles are now driven. Some of these are tapered, and are used wide end forward, so as to reverse the upward slope of the roof spiles and the upper few wall spiles.

The forward cap is now supported by a pair of beams resting on short temporary posts and wedged down from a cross timber. The remainder of the sheeting below the first cap is now broken out from the top down, and the dirt pulled into the tunnel and hauled away. Additional breast boards are set under each other as space becomes available, and held in place by cleats nailed to the side spiles.

When the floor is cut to grade, side posts (legs) are set on below-grade blocks and wedged up until they take the weight of the cap. Wedges are driven between the posts and the side spiles to tighten them. Some-



Sequence of excavation and setting of liner plates in a small tunnel.

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Fig. 9-55. Setting liner plates

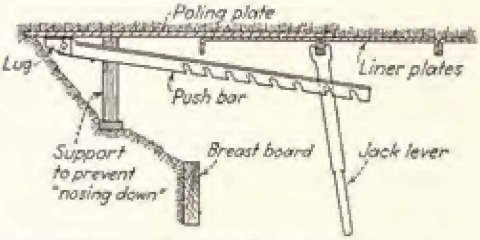

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Fig. 9-56. Steel poling plate and jack

times a trench jack must be used to force the side spiles out while setting the legs.

The next set of roof spiles is entered through the bridge slot on top of the second cap, and is driven at the same upward angle. Space for side spiles outside the legs is obtained by knocking out the wedges as the spiles are placed for driving.

All spiles should be driven skin tight (touching throughout their length) except at the corners, where 1 inch boards (lacing) are tacked on. When necessary, cracks are stuffed with excelsior, salt hay, or other packing to prevent inward leakage of soil.

Each timbering set must be braced securely to that behind it, as any shifting will severely weaken the structure.

Spiles are usually driven with a sledgehammer or air hammer. Sometimes they are jacked in—a very tedious job—to avoid jarring the soil.

If the tunnel floor tends to get muddy it should be floored, for convenience of workmen, and to avoid possible shifting or settling of the foot blocks. Sometimes floor spiles are driven if the bottom tends to boil up, but compressed air is a better way to combat this and other difficulties with excessively soft ground.

This method is relatively easy to follow in many soils, but it takes an experienced crew to get through boulders, flowing mud, and other difficult conditions.

Forepoles may also be used with steel ribs instead of timber sets.

The standard soft ground tunneling hand tool is a short-handled, round-pointed shovel, aided when necessary by a grub hoe (mattock), pickaxe, or crowbar, and often by paving breakers. Special grub hoes have one hammer face for use in driving wedges. In soft clay a curved two-handled draw knife can be used to advantage. It is pulled by two men or a power winch, and slices the clay off in strips.

Liner Plates. Corrugated steel liner plates, curved to match the tunnel rim, and supplied with drilled bolt holes in flanges or overlaps for fastening to each other, are increasingly used for soft ground tunneling. They are made in various sizes, with 16 x 36 inches in common use. A plate of this size made of ⅛ inch metal weighs about 27 pounds, and if ¼ inch stock, 53 pounds. Short plates are available for fitting into the tunnel circumference.

Stiffening ribs are used when the tunnel is over 10 feet in diameter, and for heavy loads in any size opening. They are generally not used when the same strength can be supplied by a heavier gauge plate.

Liner plates are usually a temporary support to hold the tunnel until a concrete lining is installed, usually a matter of hours or a few days after the digging. They are sometimes "robbed" for re-use immediately before the concrete is placed. The safety of this practice depends on the character of the soil, which is a matter for engineers to pass on in each case.

Liner plates are placed from the top down. A small section is dug ahead, the

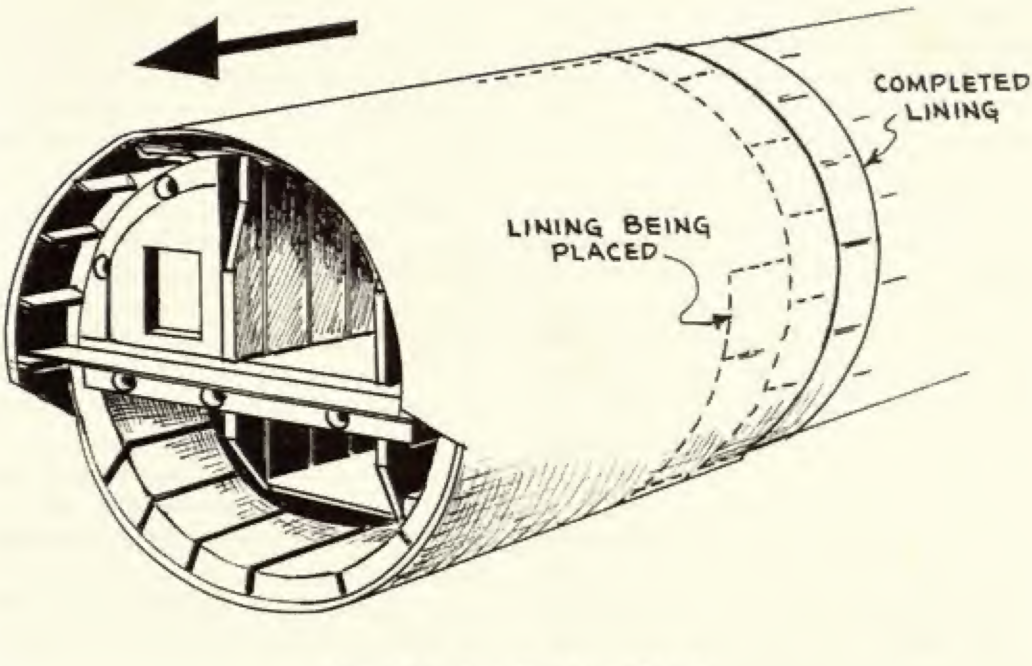


Fig. 9-57. Tunnel driving shield

center plate placed and braced with a post or jack; and then the sides dug away to place the adjoining plates. These are supported radially on cleated center blocks, as in Figure 9-55. When the spring line or base of the roof arch is reached, two 2 x 8 planks, called footing boards, are placed on each side. Wedges are driven between the two boards until they lift the arch of liner plates enough to take the weight off the jacks. The lower plates are then nailed to the boards to prevent slipping off them.

If the ground is too soft for this method, interlocked poling plates, Figure 9-56, can be placed outside and forward of the completed liner, and jacked forward from inside.

Shields. Shields have become the standard equipment for driving major tunnels in soft ground. A schematic view of one is shown in Figures 9-57 and 9-58. It resembles a tin can with an open back and controlled openings in the front. The front may be open, with grooves to allow setting a breast board or plates if necessary, or closed by a bulkhead with controlled ports. The back or tail is large enough to permit placing the tunnel lining inside it.

The shield is forced forward into the dirt by jacks based on tunnel lining. Doors in the front are opened to allow soil to flow in, or to be shoveled. In very soft ground

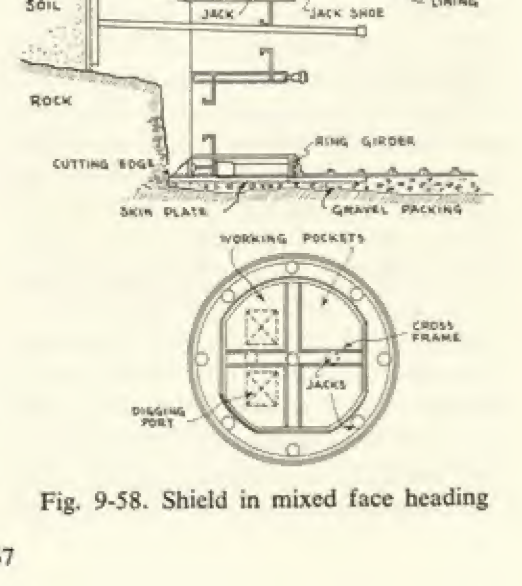


Fig. 9-58. Shield in mixed face heading

where bulging of the surface will cause no damage (as under rivers or swamps) no dirt need be taken into the tunnel, as it will be pushed aside by the pressure of the shield.

A primary lining, which is most often of bolted cast-iron segments, but sometimes of cast steel (for unusual stress), fabricated plates, concrete blocks, or timber, is constructed in the tail, which is long enough to protect a complete segment. This lining must be strong enough to not only resist full soil pressure, but it must take the thrust of the jacks that move the shield forward.

The outside diameter of the shield tail must of course be larger than that of the lining built inside it. A few plastic soils can be manipulated so as to close in smoothly on the lining as the tail moves away from it, but under most conditions the space must be filled. Failure to do so will leave the lining without proper side support, so that the arch will tend to sag.

Grout was originally the standard filler for this space. Grout plug holes were built into the liner pieces. When the tail cleared them, grout was forced into the bottom hole, with the next above used as an air vent. When grout appeared at the upper hole, the grout hose was transferred there, the bottom plugged, and injection continued. The full circumference was worked in this manner from the bottom up.

The amount of cement used makes this operation costly, and in addition the grout has a tendency to move forward along the outside of the lining and flow under the tail into the shield. Also, grout may work up to the surface, cause heaving of pavements, or break into sewers or conduits.

Gravel filling is now used to avoid these difficulties. Birds-eye gravel (uniform size, passing ¼ inch screen, 33 percent voids) or similar sizes of slag or screenings, can be blown by an air gun into the grout holes, also starting at the bottom. This will not leak into the shield nor travel far from the tunnel, but it may not fill spaces uniformly. It is therefore usually followed by regular grout. The quantity required is greatly reduced and its tendency to travel is checked by the presence of the gravel.

Compressed Air. The compressed air or plenum method of tunnel driving makes it possible to work with relative safety in soft mud and under bodies of water. The principle is that the inward and downward pressure of water and of soils can be counteracted by increasing the outward pressure exerted by air in the tunnel.

The rule of thumb is that each ½ pound of air pressure over atmospheric will support a one foot height (head) of water. Actually, the pressure required is often far less, because of the stability of the soil, restriction of water passages, and other factors.

The extra pressure is built up by low pressure compressors (converters) at the surface, and piped through a retaining bulkhead into the tunnel. Men and materials are passed through this bulkhead through one or more locks. Air in the tunnel may leak out through the soil as fast as it is supplied, or may be exhausted from the heading through a blowline.

A lock is a passageway between two airtight doors. In entering the tunnel the outer door is opened to admit men or materials. It is then closed, air pressure is raised to match that in the tunnel, and the inner door opened to complete the passage.

For exit, valves are opened to bring pressure in the lock up to that in the tunnel. The inner door is opened, the traffic moved into the lock, and the door is closed.

Air is then allowed to escape from the lock until it is at atmospheric pressure. The outer door can then be opened.

This device permits maintenance of pressure in the tunnel, and limits traffic air loss to the relatively small amount in the lock at each use.

It is best practice to have at least two locks, one for men and one for materials. The man lock should be large enough for the whole crew, and must have valves by which pressure can be closely controlled so that it will drop gradually for minutes or hours while men leaving the tunnel are in it. This process of gradual reduction, called decompression, is necessary to prevent nitrogen dissolved in the blood from being suddenly liberated to cause a painful and sometimes fatal ailment called the bends.

There may also be a small emergency lock, high in the bulkhead so as to be the last place flooded. This is left open to the high pressure, so as to be ready for immediate use. One or more cross partitions may be placed in the crown to hold air pockets in case the tunnel should be flooded.

The materials lock should be long enough to accommodate hauling units of the size used. It may be small, so that one car at a time is pushed by hand in one end, and then pulled out the other, or it may be as much as eighty feet long, to accommodate a train and a locomotive. Lock construction is expensive, but a liberal size speeds work greatly.

Fire danger under high air pressure is severe. The extra supply of oxygen in close contact may cause even wet wood to burn vigorously. Smoking and other fire hazards must be avoided, and there should be a liberal supply of fire extinguishers, and fire hose connected to high pressure water.

Clay reacts most satisfactorily to compressed air, as it is so nearly impervious that it is well supported by the air, and seals it in. Primary bracing may not be required before placing the permanent lining.

On first exposure to compressed air, silt acts like clay, but it then tends to dry out and crumble off at the top, and to turn to mud and flow at the bottom. The higher the tunnel, the greater the differences between top and bottom behavior.

This is because the air pressure is the same on all parts of the tunnel rim, but the head of water that tends to force water into the tunnel, or resists its being forced out of the lining soil, is much less at the top than at the bottom. A partial cure for the difficulty is to excavate the upper or arch section first under low pressure, install liner plates or other support; then increase pressure and dig the bottom. Once a full lining is installed, the unbalanced condition becomes unimportant.

In sand the air penetrates several feet at the top, and leaves the bottom wet enough so that boards have to be stuffed with excelsior to stop sand runs. The best cure for this condition is to drive well points ahead of and below the face, and keep the lower sand dry until lining is placed.

Air will escape in any formation except tight clay, and will reach the surface by following porous veins, old wells, or even sewers. It is best conserved by getting the lining in immediately after the digging. Airtightness of the lining is not automatic, however. Grouting outside it (which is necessary for firmness also) and painting the inside of concrete with cement and water greatly reduce leaks.

Liner plates may be made airtight by spreading wet clay along the joints. Building paper can be used on wood lagging.

About 20 cubic feet of atmospheric air per minute are required for each square foot of face area, with an additional allowance for losses through the locks.

Blowouts. Sometimes the compressed air in the tunnel blows out the surface. This is particularly likely to occur in shallow tunneling in soft underwater mud. Any outward leak must be immediately plugged with any material on hand, valuable or otherwise. From the outside a blowout can be prevented or stopped by dumping enormous quantities of clay from barges.

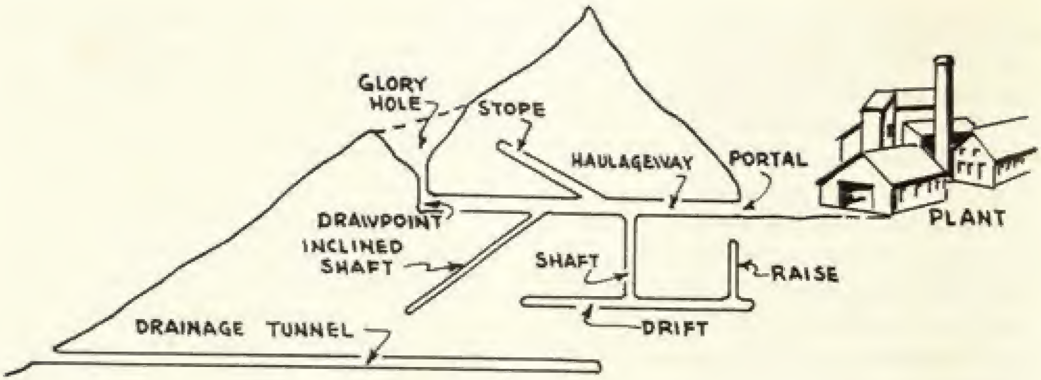


Fig. 9-59. Mine shafts and tunnels

The blowout can be disastrous in itself, hurling men and equipment up into the water. The immediate drop in pressure allows water and mud to enter the tunnel, threatening those in it with drowning or suffocation. A job "lost" in this manner is expensive and tedious to resume, and sometimes driving can be more easily done on a different route.

MINING

A mine is an excavation made in order to obtain (recover) material that has valuable chemical or physical characteristics. If it is an open cut project, it may be called a pit or a quarry. Strictly speaking, a quarry is usually concerned chiefly with a material desired for its physical characteristics, as trap rock for road aggregate. However, if a quarry goes underground, it is called a mine.

The problem of mining is to get the highest possible percentage of the pay material out, at minimum expense. In some cases, the best system is confine excavation almost entirely to pay dirt, even if it requires a maze of small and irregular tunnels. In others it is more efficient to blast and remove a hundred feet of overburden so as to expose only a few feet of ore.

The first step in deciding upon an approach is to find how much ore or other pay material there is, exactly where it is located, the extent to which it is interrupted by other materials, and its physical and chemical characteristics. This information may be required not only to determine whether the deposit is worth mining and the method, but also the type and size of any processing plant required.

Mineral Deposits. Exploration is very complex, because of the number of factors that influence distribution of minerals. Sedimentary rocks are built in more or less horizontal layers, but may then be folded, twisted, or even turned upside down. Faults are breaks that extend across the layers, and are made by movement of whole blocks of the earth's crust. They may be a single clean sliding plane, or a width of hundreds of yards in which the rock is smashed up. Movement along a fault may be a fraction of an inch, so that the same formations are found on each side, or several miles, so that one section of a deposit may be at a great distance, or lost entirely. Movement may have taken place in the ancient past, or might occur from time to time during mining.

Most metallic minerals are associated with invasion of formations by molten rock from below. If fluid rock reaches the surface it becomes the lava, ash, and other usually valueless materials associated with volcanoes. If it stays far below, it hardens gradually into granite or other coarse grain

Fig. 9-60. Diesel mine hauler

rock, and while cooling may give off great quantities of minerals, in fluid or gaseous form, that penetrate the surrounding rock for miles. The weak or porous streaks through which they move and in which they are deposited, are the miners' pay veins. Parts of the main mass may become mineralized, often resulting in an extensive but low grade ore body with rather uniform composition.

One area may undergo several successive periods of mineralization, the later ones reworking, removing, or enriching some of the earlier deposits. When the area cools sufficiently ground water becomes active at dissolving, transporting, and redepositing material.

The result of these factors is that underground structure is often extremely complex, and while exploration can give a general picture of what to look for, only very extensive (and expensive) diamond drilling, or the actual removal of the ore, will give the complete story. Access to formations is often obtainable only by the hardest and most costly type of digging—hard rock tunneling.

Exploration. There are a great many methods of exploring an area for valuable minerals. Until rather recently most deposits were found by surface inspection and sampling of the ground. Men on foot or horseback found pay outcrops, pieces of them below or downstream, or formations associated with them. Major finds are still made in this manner, but complex techniques have become more important.

A search may start with studies of geologic maps indicating more or less completely the rocks to be found in a region. Inspection and photographs from planes may reveal promising areas, which can then be scouted on foot. Test holes can be made with almost any tool from a pickaxe to a diamond drill. Radiation-sensitive instruments such as the Geiger counter are used to locate radioactive deposits. Local changes in gravity may indicate metallic ores.

A very interesting method is seismic

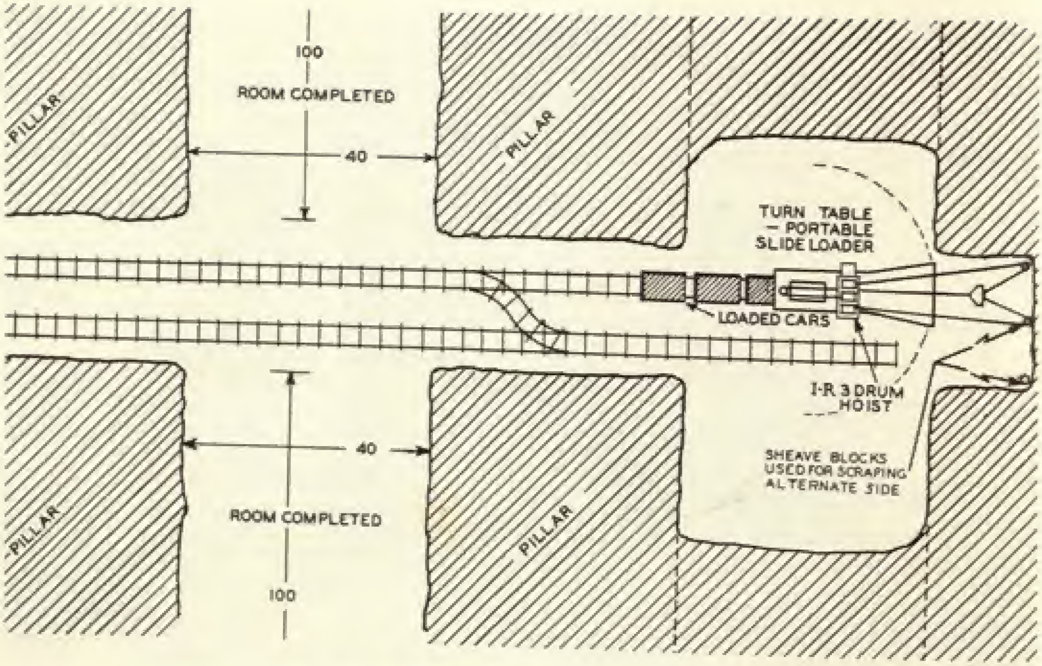


Fig. 9-61. Room and pillar excavation

prospecting. A deep hole is made, usually with a diamond drill, and a heavy charge of explosives fired in it. Sensitive instruments at selected spots in the area record the time and pattern of the resulting earth waves, which indicate the nature of the ground through which they pass. The information may be used directly in locating oil and some other deposits, or in working out underground structure to indicate the location of veins whose outcrops are confusing.

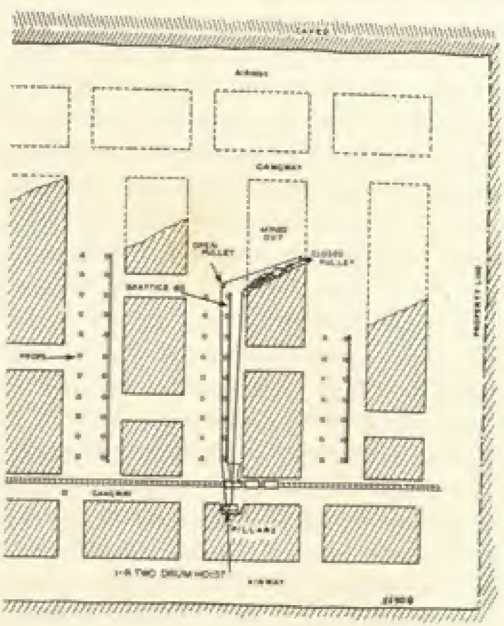


Fig. 9-62. Pillar robbing with drag scraper

Following the Ore. When mining has started, with or without benefit of thorough exploration, the digging is kept in the ore whenever it does not make too complicated a pattern. In general, large well financed operations are more inclined to place their haulageways and shafts for long term efficiency, where the small operator keeps in pay rock as much as he possibly can, sometimes with most unfortunate effects on later operations.

Figure 9-59 shows some of the tunnels that might be included in a mine. The main route in from the portal is the haulageway. A drift is an approximately horizontal tunnel of small size, a stope is excavation

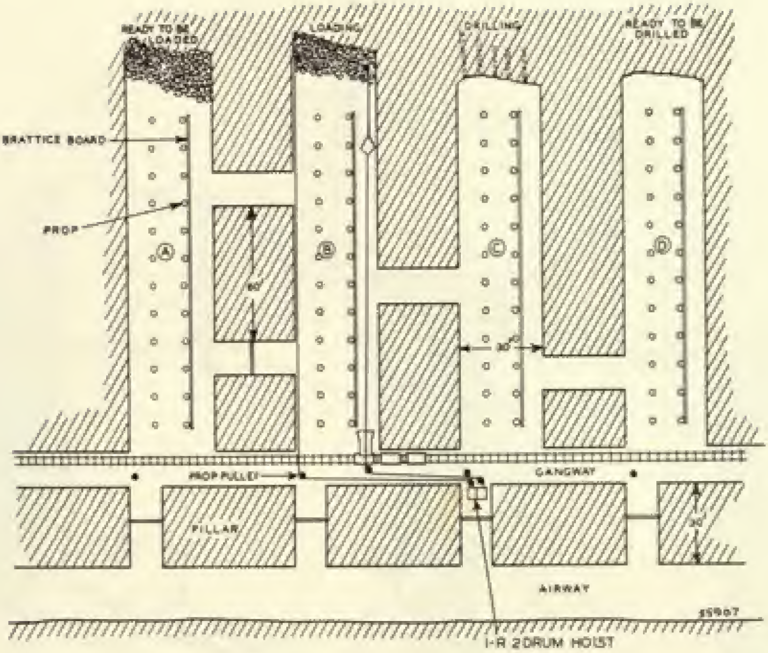


Fig. 9-63. Four-heading cycle

up an incline. A raise is a shaft worked from the bottom. Drainage tunnels, sometimes miles in length, are driven to save the cost and danger of heavy pumping inside wet highlands. The glory hole is a shaft enlarged from the top, with the muck descending by gravity to a floor from which it can be loaded by machinery. This loading area is a drawpoint.

Any of these except the glory hole may be in either ore or non-pay rock. They are contracted to minimum dimensions (which for a haulageway may still be quite large) when in country rock, and are expanded and supplemented by side drifts when in ore. If a vein is too narrow or too low for working space, excavation may include enough other rock to give head or side room.

The "arch" of the rock (the span of roof that can be allowed between walls or pillars, with or without timbering) and the height of the veins are important factors, as they determine the yardage (called tonnage underground) that can be taken out at one stand. Larger volume and working space permits use of bigger and more efficient machinery.

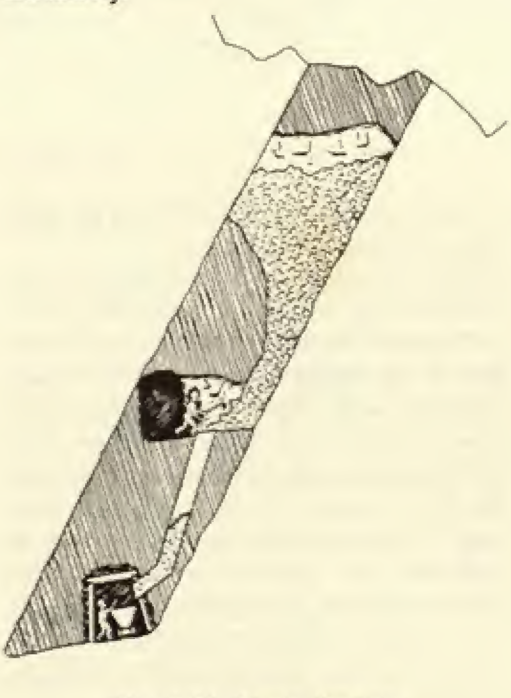


Fig. 9-64. Chute loading

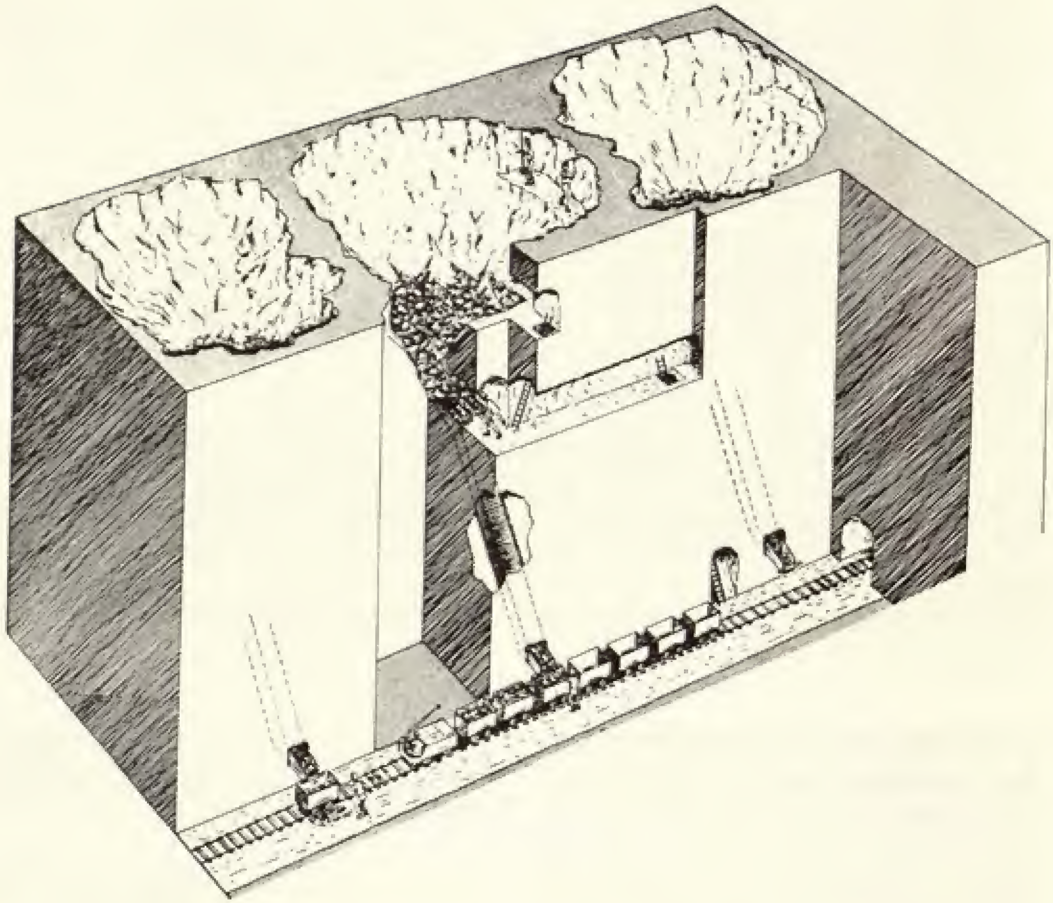


Fig. 9-65. Multiple chutes

The portal in Figure 9-60 is in oil shale with excellent self support.

ROOM AND PILLAR EXCAVATION

The most expansive underground operation is to excavate corridors and cross-corridors, as in Figure 9-61, leaving pillars to support the roof. If the formation is of sufficient value, the corridors can be back-filled to support the roof, and the pillars dug out. The fill may be non-pay material excavated in tunnels, waste from the processing plant, or outside borrow. When circumstances permit, the pillars may be pulled and the roof allowed to collapse, as in Figure 9-62.

If it is known in advance that all pay rock will be removed, the cross-corridors may be reduced to ventilation openings so that there will be parallel chambers

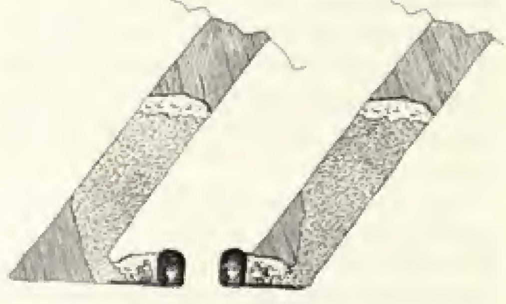


Fig. 9-66. Head and foot wall draw points

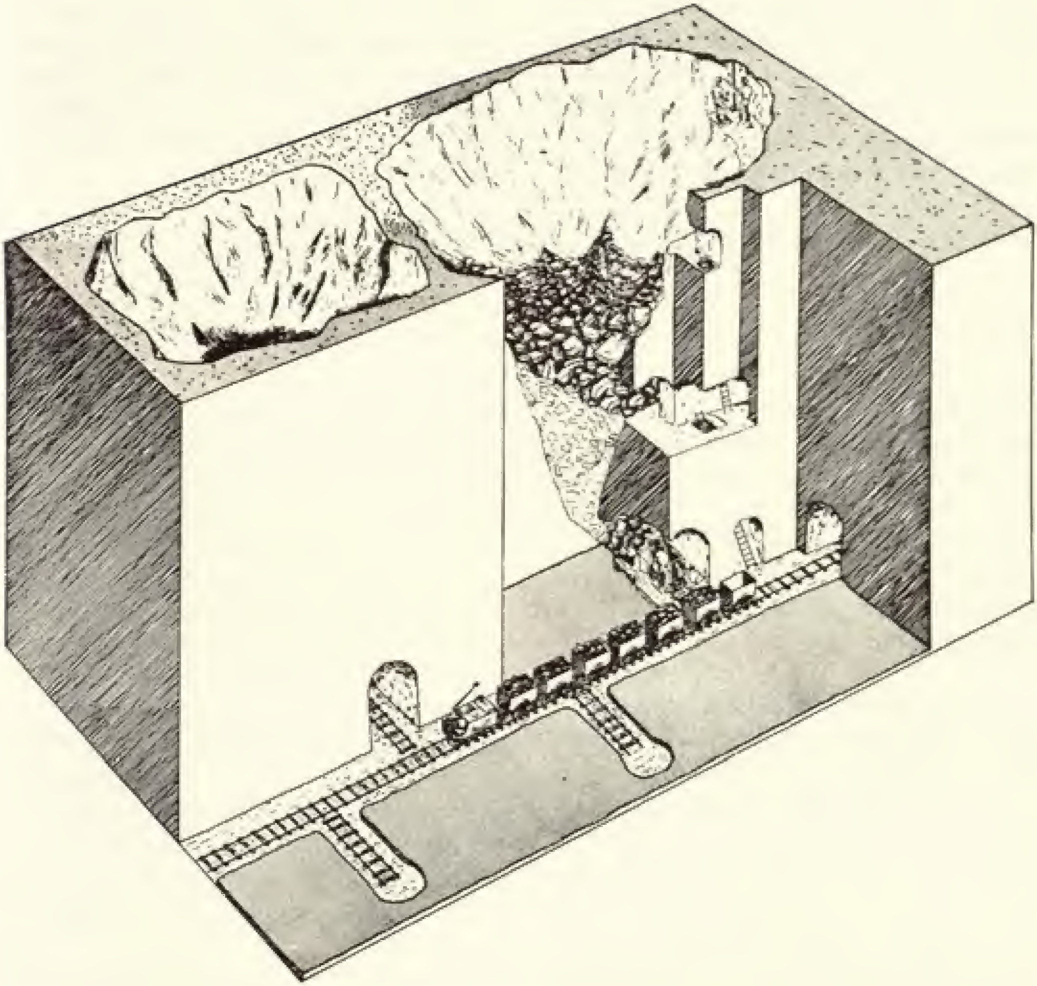


Fig. 9-67. Draw point loading

separated by ribs of similar width as in Figure 9-63. If the corridors are backfilled, the ribs can be removed in a new tunneling operation, with fewer complications than are involved in pillar extraction.

Room and pillar work is commonly done by machinery, and in some mines, by large machinery, such as shovels up to 2½ yards.

Overhead Mining. When the haulage tunnel runs at a lower level than the pay deposit, the ore can be blasted and then fed by drag scraper and/or gravity to the haulage equipment. One technique involves use of a timbered chute from the working to the haulage level, with a gate called a grizzlie at its lower end. Fragmentation must be fine enough to enable the broken ore to slide down through the chute after being pushed or raked to it. A mine car is stopped under the chute, the grizzlie opened until it is full, and then closed until the next car is in position. There may be several chutes, so spaced that each will open squarely over one car of a parked train. See Figures 9-64 and 9-65.

The drawpoint loading method, Figures 9-66 and 9-67, utilizes a large untimbered

stope (inclined tunnel) so shaped that broken ore slides by gravity to the lower floor but it is restricted against spreading out on it. This ore is dug by mechanical loaders (Eimco Rocker Shovels in these illustrations) and loaded into cars or onto conveyors. The expense of chute construction is saved, and the larger opening allows oversize pieces to slide through without jamming. Such pieces can be set aside by the loader and blasted when it will not interfere with mucking.

CHAPTER TEN

PIT OPERATION

This chapter contains an outline of some of the principles of pit layout and operation. The term "pit" is intended to cover any open excavation made to obtain material of value, whether it be coal, mineral ore, quarry rock, gravel, or fill.

Because of the complexity of the subject, treatment will have to be brief, and many operations omitted entirely.

Techniques of drainage, road building, and blasting have been discussed in previous chapters.

Most pit operations are started with the removal of soil or rock lying over the deposit to be mined. The problems involved in stripping will therefore be considered first.

STRIPPING OVERBURDEN

Overburden may include topsoil, subsoil, sand, gravel, clay, shale, limestone, sandstone, and other sedimentary deposits. In some clay pits, the overburden is partly coal, and in many coal mines it is partly clay.

The depth of overburden that may be removed depends on its character and accessibility, on the value of the underlying formation, the comparative cost of underground mining, and the extent to which the spoil can be sold or utilized.

Need for Stripping. Stripping overburden may be a very large part of the cost of mining, and a number of factors should be considered before undertaking it.

First, is it necessary to strip it? It may be possible to mix it with the product, or to separate it at less expense during processing.

For example, much run-of-bank gravel does not contain enough fines to bind it for road use, and overlying soil, if permitted to mix with it by caving, may improve its quality.

If the pit has gravel or stone screening, separating, or washing equipment of adequate capacity, soil may be dug or blasted down with the pay dirt, and separated as part of the regular processing. In this case, thorough clearing is necessary as sod and brush clog screens and crushers.

Loose sand and gravel cannot be dug underground, but with other deposits, careful investigation should be made of the latest methods of underground mining, and a comparison with open cut costs made.

Utilization of Spoil. If the land must be stripped, the next question is possible profit or use to be obtained from the material. Near large cities, topsoil can often be sold at a higher price than the regular pit product. This may also be true of peat deposits.

Any substantial layer of clay, or fine earth, should be sampled and analyzed. Clays which are superficially similar in appearance are used in widely different products, such as fire, paving, and common brick; tile, pottery, portland cement, flux, mud for rotary drills, and specialized functions in chemical processing.

Good deposits of some of these earths are very rare and are valuable. Common clays may be in demand because of local shortage, or industry using them may be developed.

Limestone is often found in overburden, and it is extensively quarried for crusher rock, building stone, and cement manufacture.

If it is not possible to get good prices for any part of the spoil, it may still be possible to get enough for it as fill to repay some of the stripping cost. The stripper is in a good competitive position because he has to pay for digging, and often for dumping as well, and is better off selling for a fraction of the excavation cost than not selling at all.

The limiting factor is his additional cost in making the spoil salable or delivering it. If selective digging that will slow his operation, or finer fragmentation, is required, or if he must truck material which otherwise could be cast, the salvage may cost more than it is worth.

When the spoil is being removed in trucks or scrapers, and no market exists for it, and it is not practical to set up any plant to process it, it might be used for real estate improvement or for good will.

Swampland along railroads or highways can often be bought very cheaply, and can be converted into valuable industrial sites by filling and grading. Filled land near towns may be sold for residential purposes.

Pits are frequently unpopular with the neighborhood because of blasting, heavy trucking, or dust. Local authorities may impose restrictions which would make operation more expensive or impossible. Under any circumstances, cultivation of local good will is sound business practice.

Fill which is being hauled and wasted can be utilized to reclaim land for parks or parking areas, building road or airport fills, and blocking gullies. Topsoil can be used to enrich farms, gardens, or lawns.

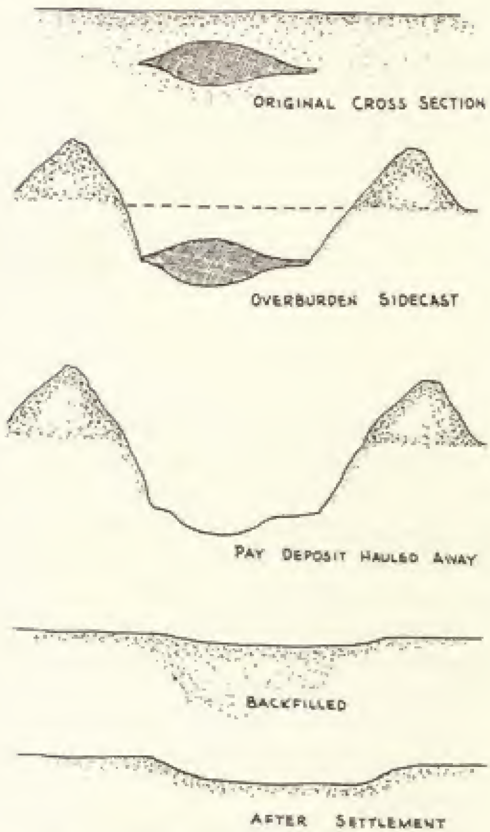


Fig. 10-1. Steps in strip-mining a lens

However, there is danger in such work of getting into much greater expense for extended hauling and grading than anticipated, so a careful study should be made in advance. The people or community benefited will often be willing to pay at least these extra costs.

SIDECASTING

When the spoil cannot be utilized, the cheapest way to move it is by sidecasting—that is, to pile it alongside the cut within dumping range of the excavators. This disposal is possible when the pay formation has only a narrow exposure, or can be worked in narrow strips, so that the overburden can be economically moved across the pit, from the unopened to the worked-out area.

Sidecasting is generally not practical in working thick layers of quarry rock or mineral ore, because of need for wide working space below the face. Its best known application is in the strip mining of bituminous coal.

A number of states now require grading of spoil piles and breaking down of walls of worked-out pits. This work should be included in cost calculations.

Figure 10-1 illustrates the process of stripping, mining, and backgrading a narrow lens. It consists of three operations aside from the drilling and blasting frequently necessary. Top material is cast out of the way, pay material is dug and trucked away, and the top pushed or cast back in.

Progressive stripping of a wide deposit, as in Figure 10-2, resembles the action of a gigantic moldboard plow, taking slices off the high wall and laying them against the spoil heap. Mining is done between trips.

If the spoil piles are smoothed over where they fall, without substantial re-moving, the original grade will be raised in a ridge parallel with the beginning of the work, and lowered at the last cut, these changes corresponding to the land and the dead furrow of the ploughed field.

In general, areas of blasted spoil have a coarse, rocky, well drained soil, with good supplies of phosphate and potash, but little or no nitrogen or humus. With proper care they are expected to make good forest land.

Bulldozers. Where the deposit is shallow and the pit narrow, bulldozers make good stripping tools, particularly when the land slopes across the pit. Figure 10-3 shows a sequence of operations. This can be repeated in successive strips across the deposit if conditions remain the same.

Such shallow overburdens seldom require blasting but use of a rooter may speed the digging.

It will be noted that this machine backfills the face of the pay layer so that work

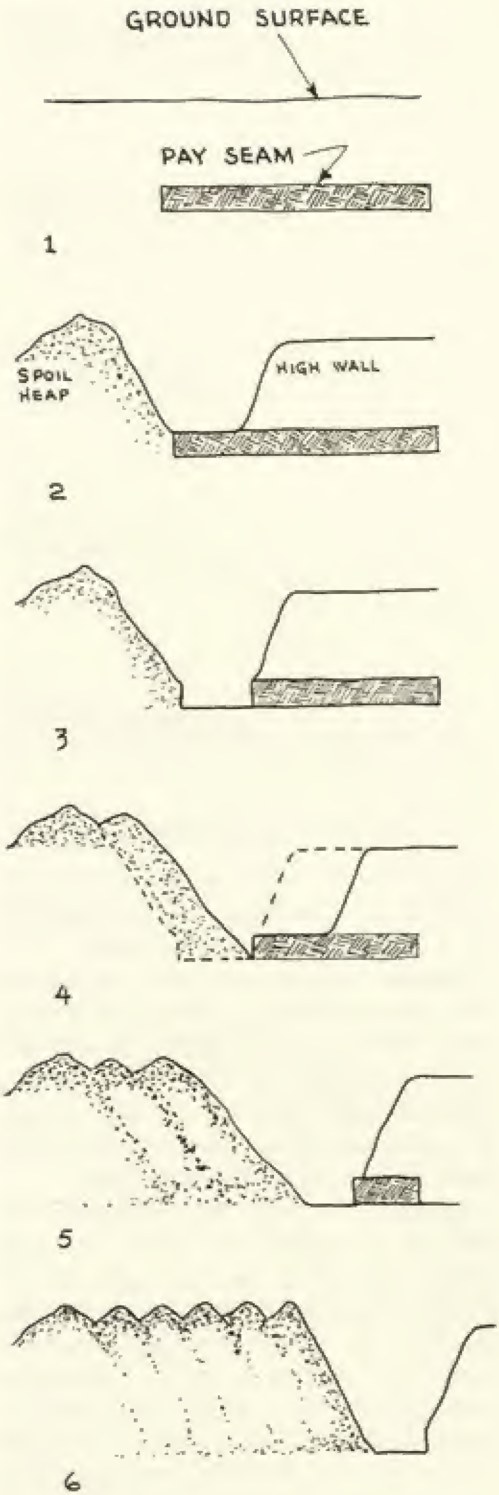


Fig. 10-2. Strip-mining a horizontal bed

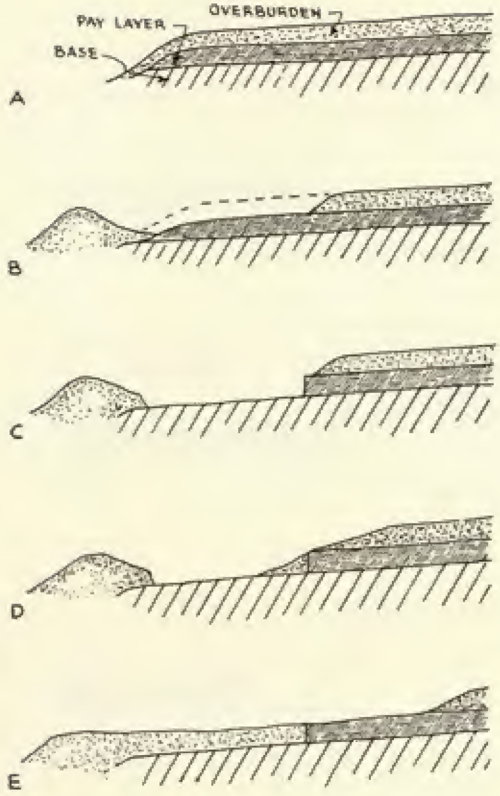


Fig. 10-3. Bulldozer stripping

must be done from the surface of the seam.

Bulldozers are also essential auxiliary tools in the heavier stripping work.

Scraper. Scrapers, or pans, are used in sidecasting, haul-away, and combined stripping. Their best application is to soils not requiring blasting, or which blast into fine fragments, and which are not deep enough to justify the use of shovels with enough reach to give the pit width required.

Figures 10-4 and 10-5 illustrate two methods of scraper use. These are considered sidecasting since the spoil piles are placed immediately behind the pit, but otherwise the work is identical with haul-away with the same machines. A particular problem that becomes more important as depth increases, is maintenance of haul roads across the pit and up the spoil bank.

In 10-4 the high wall is smoothed off and the outcrop of the pay formation covered

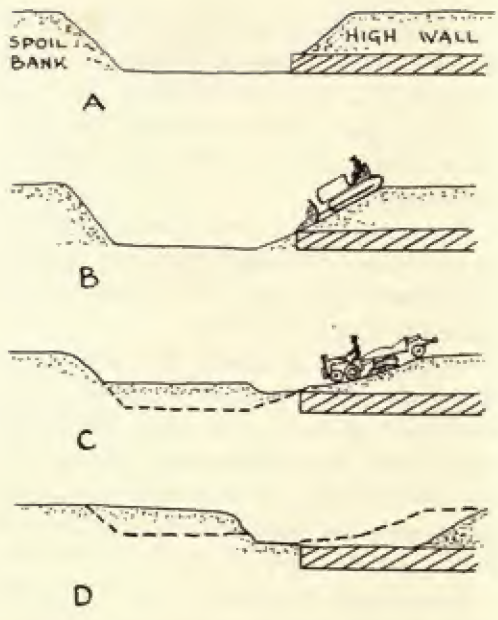


Fig. 10-4. Stripping shallow overburden with scrapers

by bulldozers working down the slope. The pans then dig the high wall, working downhill, and build their fill on the full width

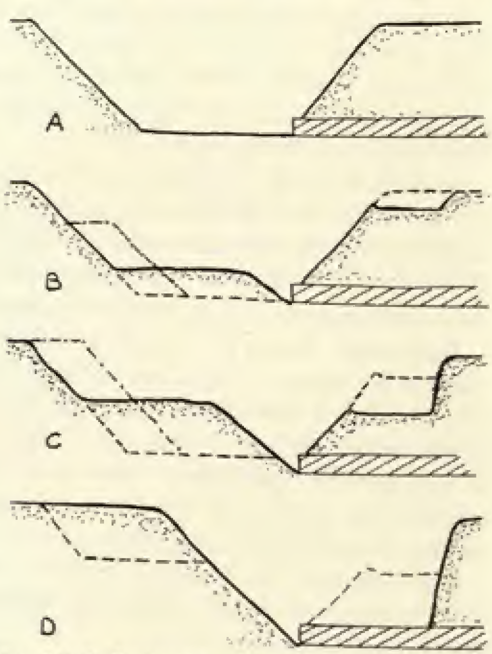


Fig. 10-5. Stripping deep overburden wtih scrapers

of the empty pit, working against and parallel to the spoil bank.

In 10-5 the digging and spreading are both done the long way of the pit. The seam outcrop is crossed only occasionally by haul roads, the rest of the face being left exposed.

Lengthwise digging is well adapted to combined operations. If only part of the overburden were to be removed by the scrapers, and the balance by shovels, a narrower fill would be made, as indicated by dot-dash lines. The scraper work would thus serve to reduce the depth to be handled and the distance it would have to be thrown.

Scraper cuts such as shown in 10-5 (B) and (C), are frequently made to dispose of loose or soft overburden on rock which requires blasting. This reduces the drilling footage, eliminates the need of casing large blast holes, and permits use of wagon drills on the exposed rock.

Fill from such preliminary cuts is often used in grading old spoil banks.

Dipper Shovel. For sidecasting work, dipper shovels are equipped with extra long booms and sticks to increase reach. These are compensated by extra counterweight and power or smaller buckets.

Crawler mounted stripping shovels are made with bucket sizes from three eighths to forty yard capacity. In any size, they may be used either for sidecasting, or for loading trucks or trains, which stand in the pit or on comparatively low walls.

Small and medium stripping shovels are generally more or less standard units that can be readily transported from job to job. Large ones are likely to be custom made, shipped to the job in pieces, and erected at considerable expense. Their high cost is only justified when enough work is available to repay it.

Diesel, diesel-electric, and high-line electric power are used in medium and large units. Separate electric motors may be used

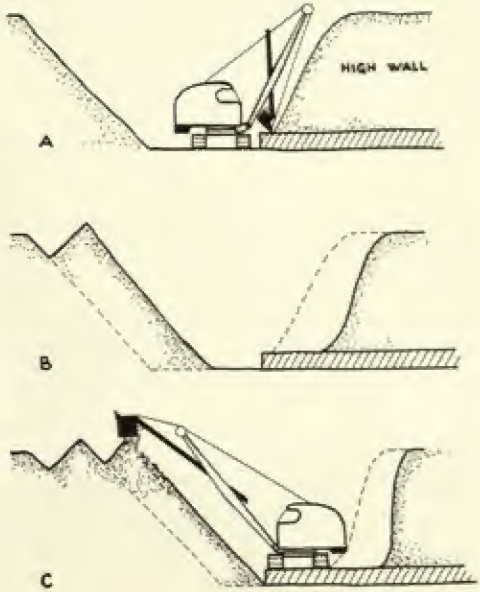


Fig. 10-6. Two-trip stripping with a dipper shovel

for each shovel function, or one motor may power two or more gear trains.

For casting, reach must be increased with the depth of overburden, as the slope of the pile progressively narrows the work area in proportion to top width of the cut. Increases in power and bucket capacity are

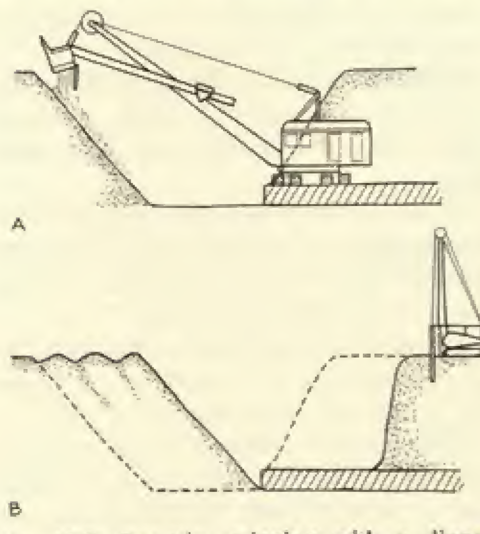


Fig. 10-7. One-trip stripping with a dipper shovel

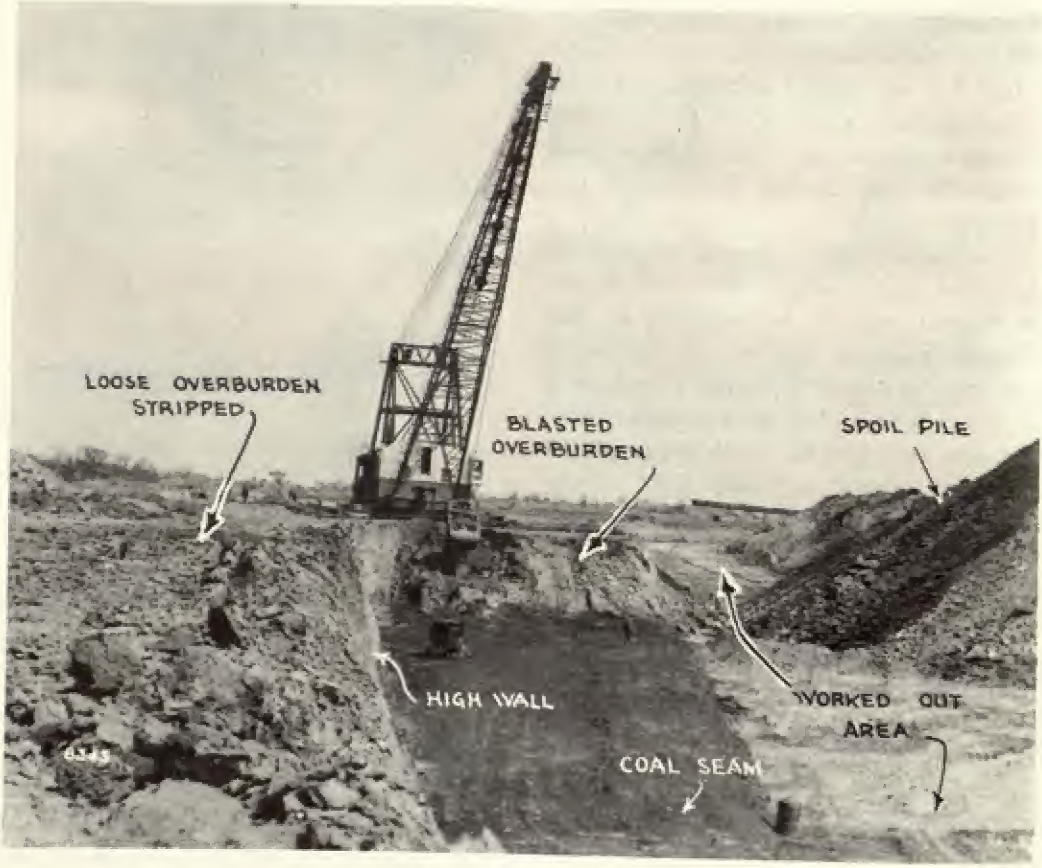


Fig. 10-8. Stripping with a dragline

required for digging harder and coarser material, and for greater output.

The large stripping shovel can dig harder unblasted material, or more coarsely broken blasted rock, than any other excavator.

A shovel may make one, two, or more trips to clear a working area. It may be worked from the coal or pay seam, or from the floor left after its removal.

Figure 10-6 illustrates two-trip stripping by a shovel, and 10-7 one-trip by a bigger one. Maximum swing required is 180°

The shovel is followed by one or more clean-up bulldozers. The toe of the high wall is scraped back for convenience of drill crews, and the surface of the pay seam is cleaned of material left or dropped by the shovel, or which has slid or rolled from the pile. This debris is pushed into the spoil pile.

Coal may be injured by grousers of heavy bulldozers. Rubber tired dozers, or crawlers with the grousers trimmed back or covered by street shoes can be used to avoid damage.

Dragline. Stripping draglines are available in sizes comparable to those of the shovels. Power plants are similar. Crawler or walking mountings may be used. The walker rests directly on the ground and moves by eccentric movement of shoes on each side. It is safer for use on high or loose banks because its ground pressure is low and it can turn to walk without exerting any side thrust.

Walkers are not adapted to use on pit floors because they can only walk away from the boom so that they may be trapped if unable to swing freely. In addition, they are usually wider than crawlers of the same weight.

The dragline strips by moving along the high wall, parallel with the pit, digging behind it and casting onto the spoil pile, as in Figure 10-8. Maximum swing is about ninety degrees. Standard practice is to dig within the radius of the boom point.

Large draglines can dig hard and coarse formations but are somewhat less efficient in them than shovels.

Draglines can load part or all of the spoil into trucks or trains, on the wall or in the pit. They can dig selectively from the top down, handling different formations in succession from one stand, providing blasting has not disarranged and mixed them too badly.

This ability makes possible a rough division of the bank into select material to be hauled away, and waste to be sidecast.

Clean-up bulldozers follow immediately after the dragline and push their loads within reach of its bucket.

Stacker. Stackers are mobile elevating belts. The belt is carried in a boom which can usually be raised, lowered, and swung while operating, and may be adjustable in length as well.

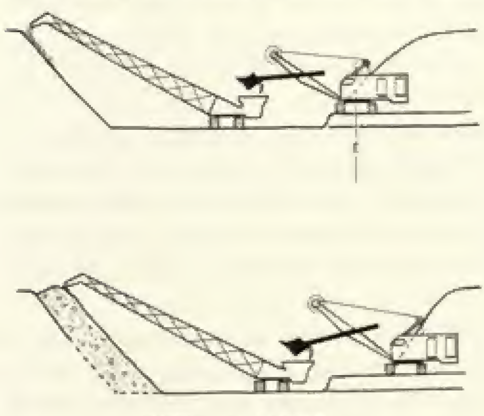


Fig. 10-9. Dipper and stacker handling overburden

Figure 10-9 illustrates the use of one of these machines in conjunction with a standard-boom shovel. The shovel digs the bank and dumps in the hopper, from which the belt carries it to the spoil bank.

Dug soil can usually be moved more economically by a conveyor belt than by swinging a shovel heavy enough to carry a boom of the same range. However, the stacker is not as flexible and will not handle as coarse material as a stripping shovel or dragline.

The stacker is also used in the pit for loading trucks up on the bank.

Double Casting. If a space is required which is wider than that which can be stripped by available shovel and dragline equipment, and the spoil is too coarse for scrapers, a shovel may be used to swing the spoil out onto the pit floor, and a dragline to pile it on the bank. The illustration in Figure 10-10 is of a quarry requiring a wide working area below the face.

For best results, the two machines must

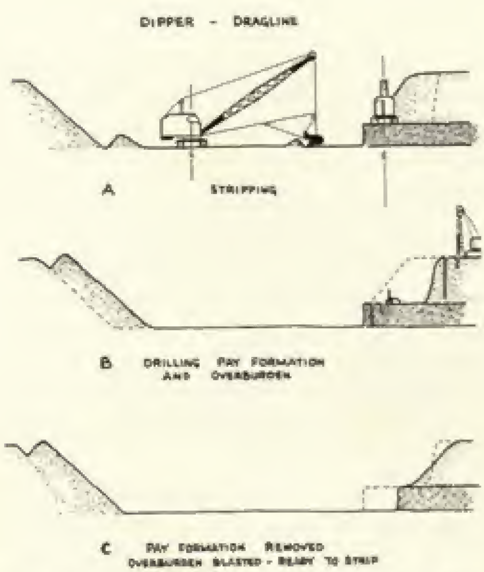


Fig. 10-10. Dipper and dragline handling overburden

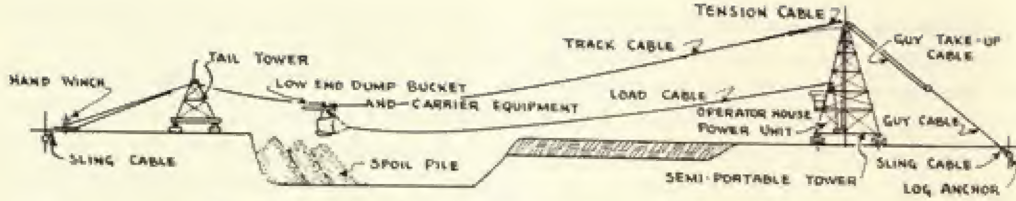


Fig. 10-11. Overburden removal with a cable excavator

work together as, if the dipper is allowed to build a substantial windrow, the dragline will need a longer reach to get to its far edge.

A dragline may also be operated on the previous spoil bank to take off the top of the pile being built by a shovel, to increase its disposal capacity.

The extra expense of double casting limits its use to special conditions.

Cable Excavator. Overburden can sometimes be economically stripped with slackline cableways. A long pit will require a mobile or portable tower and means for easily moving the tail tower.

A good practice is to locate the heavy head tower on undisturbed ground, and the tail tower on the old spoil, as in Figure 10-11. The bucket and dump mechanism

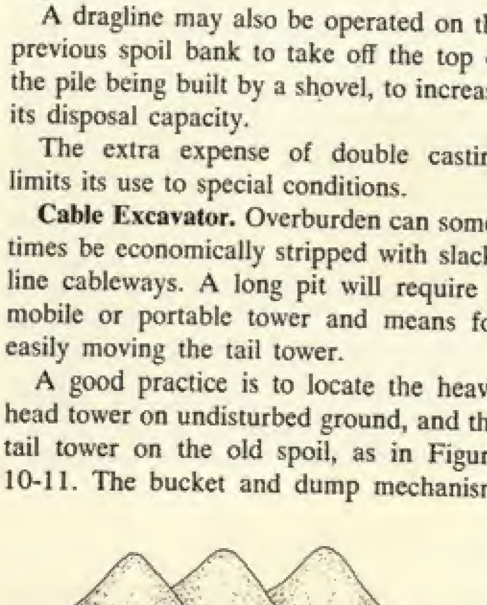


Fig. 10-12. Piling spoil

are made to dump at the low end, and digging is done toward the head tower to avoid dragging spoil over the face.

Slacklines are best adapted to wide cuts. They may be assisted by rooters or blasting in hard deposits.

If access to the face is not required, a power drag scraper can be used to pull the overburden into the old pit.

Grading Spoil. The spoil banks from light stripping operations can be leveled by bulldozers, scrapers, or graders. However, the huge machines used in heavy stripping leave such large coarse piles that the biggest dozers cannot reduce them economically.

The problem is largely a new one, as prior to legislation of the subject, most of the stripped areas were left as permanent wastelands. Techniques are still in the experimental stage.

There are two ways of approach—one, to do original piling in such a manner that a minimum of grading will be required, and the other, to strip in a conventional manner, then work over the result.

If a dipper shovel is moved short distances frequently, the high peaks of its spoil ridge are greatly reduced as indicated in Figure 10-12 (A) and (B). The more even ridge top is the more readily broken down by a bulldozer working along its crest. The trough is also more regular and easier to grade out as a haul road.

If the boom and stick are longer than is required by the height and slope of the bank, the ridge and trough surface can be eliminated by building out level with the old bank, (D) and (E), instead of heaping toward the pit, as in (C). Accurate grad-

ing cannot be expected in such overhead dumping, but the bulk of the irregularities can be eliminated.

A dragline with extra boom length can build a flat top pile by dumping against the bank near the top at full reach, and building out the edge by shorter or longer swings as required. Approximately the same result can be obtained with a slightly shorter boom by throwing some spoil.

Another dragline procedure, requiring extra clearance at the pile foot, is to drag the top of the completed pile onto the slope to the pit, as in (F) and (G).

If the machine can be reeved so as to have a live boom, grading off spoil heaps may be made much easier as the reach can be varied by raising or lowering the boom.

When old piles too large for bulldozers must be leveled, a large dragline can be used to drag them down and spread them, in the manner described in Chapter 6 for leveling spoil heaps from ponds.

Another system is to cut rough haul roads through the troughs, and build them up with spoil hauled from fresh stripping. Scrapers usually do this more economically than trucks as they can spread as well as dump. The troughs may be entirely filled, or just brought up far enough to enable dozers or other machines to take down the tops.

STRIPPING AHEAD OF PIT EXPANSION

A pit in a heavy deposit usually expands rather slowly, and stripping work is done at intervals, often by the pit machinery in slack periods. Stripping may be postponed until the face is pushed back against the overburden, as in Figure 10-13 (A).

Stripping may then be done by either pushing into the pit and loading from the bottom, or throwing back with a dragline, hoe, or clamshell. Consideration should be given to the question of caving of high banks. Bulldozers are most apt to cause

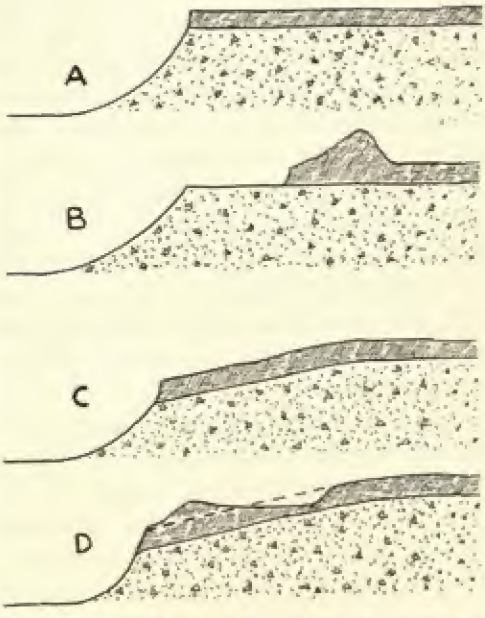


Fig. 10-13. Stripping on edge of expanding pit

collapse but may not be damaged. Revolving shovels are both heavy and easy to overturn, and should be kept well back from doubtful edges.

Once the edge is cleared, as in (B), the burden can be moved back farther by recasting with the dragline, pushing with a dozer, or carrying in trucks or scrapers.

If there is no definite boundary to the pit area, pushing back the soil and leaving it, which is generally the easiest disposal at the time, will cause greater expense when it has to be moved again.

If the ground above the pit slopes up, it may be necessary to cut a platform parallel to the edge to support the dragline, as in (C) and (D). Because of the inefficiency of casting uphill, the platform should be used as a road for hauling the spoil.

It is vital to pit efficiency to keep overburden stripped far enough ahead to be out of the way in rush periods. Failure to do this often results in spoiling or losing valuable material, and in inability to fill important orders.

Waste Dumps. When fill is hauled away, the techniques of digging and loading are about the same as those for paydirt, so that a separate discussion is not required.

The requirements for a waste dump are that it be as close to the digging as possible, and require a minimum of grading and supervision. These needs are often answered by an abandoned section of the pit with access to the top of a high face. Very high fills may build out so slowly that spreading equipment is required only at long intervals.

However, there is danger of trucks backing off the edge, or the edge itself falling away. If this danger exists, a log or timber support or bumper should be placed at each of several dumping spots, and moved sideward or outward as required.

If it can be managed without substantial extra expense, different types of spoil should be placed in separate dumps in such a manner that they will be accessible for re-digging. Changed conditions may make previously worthless material valuable. Examples are the current reclaiming of mine tailings and slag heaps.

TOPSOIL

Topsoil is frequently the only material sold from a temporary pit. At other times, it may be a highly profitable side line, or a costly stripping and wasting problem.

In this discussion, topsoil is defined as any layer or layers of soil containing sufficient humus (organic matter) and plant food to support a good growth of grass or other desirable vegetation. It is ordinarily on the surface but is occasionally buried by flood deposits or slides.

In the eastern states, topsoils are predominantly brown in color, with a humus content between 3 percent and 20 percent by weight. Depth varies from zero on ridges to many feet in bottom lands, but is usually between four and ten inches. Division from lower soil layers is usually definite. These soils will be the basis of most of the following discussion.

In arid and semi-arid sections of the West, topsoil tends to be deficient in humus and rich in minerals. It is often difficult to distinguish from subsoil. It may occur in deep layers or deposits and in general does not obtain as high a price as in the East.

The prairie topsoils range from eight inches to several feet in depth, may be brown or black, are rich in both humus and minerals, and generally have an excellent texture.

Swamp topsoils, in any section, tend to be gray to black in color and may contain up to 85 percent organic matter. Depths vary from a few inches to hundreds of feet. The richer deposits are not topsoil as defined above, and will be discussed separately as peat.

In general, the salability of topsoil is determined more by appearance and texture than by the ability to grow crops. The average topsoil buyer will seldom have soil tested, and tests are often not as reliable as good judgment.

Topsoils with high percentages of clay or silt will be heavy, slow draining, and inclined to pack into hard lumps if disturbed when wet. Increase of humus content will soften the lumps.

Sandy or gravelly topsoil is loose in texture, drains readily, tends to dry out, and can be worked when wet without caking. Most soils fall in an intermediate structure, with variable draining and lumping characteristics.

Tilth is the condition of the soil in regard to lump or particle size. It is affected by grain size, humus content, microorganisms, and the way in which it has been worked. For most crops, a loose structure made up of fine, soft lumps is desirable.

Appearance is largely a matter of color, and freedom from lumps, stones, subsoil, and trash. Dark soils are generally preferred, with strong differences of opinion

between black and brown types. Red tinting is due to the presence of iron and has no significance in many localities. When entirely dry, topsoil loses its color and is practically indistinguishable from subsoil.

A plowed or cultivated field, or a topsoil pile will appear darker and richer when the observer is looking toward the sun than when he is looking away from it.

Testing. One test of topsoil is the observation of the type and condition of vegetation it supports before stripping. Allowance must be made for weather conditions and the type of crop. Old pastures or fields may become sod bound, or taken over by low growth, so that good topsoil will give a poor appearance.

The vigor of weed growth on piled topsoil is an excellent index to quality.

Laboratory or field tests can be made for humus content, grain size, acidity, and available plant food. Humus is measured by the ignition test to be described for peat, and grain size on screens used for testing sand and gravel.

The test for acid-alkaline balance is commonly made by pressing litmus paper against the damp soil, and comparing its new color with a chart. If the soil is dry, distilled water should be used to dampen it, as tap or pond water may give a false reading.

Acidity is expressed in terms of pH (percentage of free hydrogen ions). A reading of 7.0 is neutral, lower readings increasingly acid, and higher ones alkaline. Most plants will grow under quite a wide range of conditions. A slightly acid condition is desirable for most of them.

Excessive acidity is readily corrected by the addition of lime which can be spread on the field before plowing or disking. Soils are made more acid by mixing with humus, oak leaves, or aluminum sulfate.

Kits obtainable at garden supply stores can be used to measure available or soluble nitrogen, potash (potassium oxide), and phosphorus or phosphorus oxide. It should be remembered, however, that these chemicals are often taken up by plants, or leached out by rain, as fast as they become soluble. The real measure of prolonged fertility is the insoluble reserves that are gradually made available by soil organisms, plants, and weathering. Except for humus, which is rich in nitrogen, and often in the others, such reserves are difficult to measure.

Preparation for Stripping. The cost of properly preparing a field from which topsoil is to be sold is usually a small part of the total expense, and should increase the value of the soil so that it will either command a higher price or be more readily salable at a standard price.

Aside from clearing, field preparation may not be necessary if the soil is to be left piled long enough to rot the vegetation —usually four to six weeks of warm weather for sod—or if digging is to be done by a chain bucket loader. Plowed land is more easily and cheaply piled by a bulldozer than solid fields.

Removal of brush is described in Chapter 1. If no other excavation is to follow the topsoil stripping, medium and large trees should be left, as the amount of soil obtained from around their stumps is small, and the expense of removal and the loss of property value may be considerable.

The field should be plowed to the full depth of the topsoil, if possible, or at least deep enough to turn up most of the roots of the grass or crop. However, turning up of subsoil should be kept to a minimum, particularly if it is of a conspicuously different color. Therefore, if the topsoil depth is variable, or plow depth hard to control, it may be necessary to plow very lightly.

Plowing is usually necessary for sod and heavy crops. Disking may be enough to cut up soft light crops, and on shallow soils will avoid bringing up subsoil. Disking generally does not loosen soil deeply enough to help a bulldozer much, but may

create an ideal condition for hoe or dragline piling.

If a field is burned off, it can usually be disked without plowing. This practice is not recommended, as chopped up vegetation increases bulk and improves the quality and the appearance of the soil. However, occasionally it will be of advantage for economy in handling, or for immediate sale to customers wanting very clean soil.

After plowing, the field should be thoroughly disked so that the vegetation is chopped up and well mixed with the soil. It is then ready for stripping.

If soil is to be removed in a wet season, it may be necessary to leave some strips of sod intact to support trucks.

Noxious weeds can be reduced or eliminated by planting and turning under one or more vigorous, close growing cover crops. Buckwheat is particularly effective at smothering out.

Nitrogen Deficiency. When vegetation is turned under and mixed with soil, there is an immediate and rapid increase in the number of the microorganisms which cause it to decay. For their growth they need nitrogen. If the crop is a legume, such as clover or vetch, they will be able to obtain it as they break down the plant material, otherwise they obtain it, or as much as they can get, from the soil.

This is likely to result in temporary total exhaustion of available nitrogen. When the vegetation has decayed so that it no longer provides sufficient food, most of the organisms die and their nitrogen is largely returned to the soil.

During the interval, which is two or three weeks for fresh green material in warm weather, and longer when the material is dry or coarse, when soil moisture is deficient, or when the weather is cold, any crop which is planted will be starved for nitrogen and make little or no growth.

This effect is most severe when conditions favor rapid decay.

Buyers of topsoil containing large amounts of freshly mixed vegetation should therefore be cautioned to either allow sufficient time to elapse before planting grass seed, or to supply nitrogen fertilizer to give the plants a start. Otherwise considerable dissatisfaction may be expressed and future orders lost.

Packing Soil. The value of topsoil is reduced or lost if it is packed into lumps. Except for a few very light and friable soil types, varying degrees of damage will be done if it is worked wet, or trucked over except when thoroughly dry.

Wet working breaks down the soil particles into a structureless mud that dries into lumps and sheets. The probability of damage increases with the amount of contained water, and its severity decreases with increased proportions of sand or humus.

Packing under trucks or other heavy machinery may produce the same result by bringing water out of small spaces between particles so that it will make a mud. Trucking on rather dry soils will produce compression cakes which are usually softer than the mud lumps.

A rough test of condition may be made by rubbing a sample of soil between thumb and finger. If it smears, it is too wet, and if the particles remain separate, it is probably ready to work. The dirt turned by the plow or dozer blade should be watched for smearing, which indicates that soil is too wet.

Topsoil should not be trucked over, but it is often impossible to avoid doing it. The stripped areas may be too soft, or they may not offer enough space for maneuvering. If the latter, trucks may be routed to drive empty across the topsoil and run on the subsoil with loads.

It is usually better to completely ruin a narrow strip of soil by using it as a haul road than to damage a large area by allowing trucks to wander around on it.

Soil lumps are completely broken down

by freezing and thawing and usually disintegrate slowly in wet seasons. If still on the field, roots of a cover crop, or sometimes only a thorough rolling or disking, will reduce them.

If absolutely necessary, a hammer mill shredder of the type used for humus can be used to pulverize them.

Piling. The standard tool for piling topsoil is the bulldozer. The shovel-dozer does the work in the same manner, but rather more efficiently, as it can make rather high piles without walking on them, and can back soil out from corners.

When piling is done in advance of loading, the standard practice is to heap the soil in windrows (long piles). These may be run up and down the slope so as not to interfere with drainage; or across it to keep in uniform soil types, or for convenience in trucking. It may be necessary to make occasional breaks in windrows to prevent ponding of water above them. Piling should be started at the entrance to avoid trucking over unstripped areas.

Windrow size will vary with loading requirements and soil depth, and the size of the bulldozer. Small, closely spaced ridges are most easily piled but loading machines work best in large high piles. Large dozers and deep soil favor building big piles.

Building of the piles is described in Chapter 4. The width of the windrow should be figured in advance so that work will not be wasted by digging inside the pile area, then refilling.

If piles run up and down a slope, stripping should be done from the top down to correct any tendency to gouge on the lower side. If piles run across the slope, most or all of the soil should be moved downhill.

Under ordinary conditions, the top of the topsoil is piled first, so that the operator can concentrate on moving big loads without much concern about accurate work.

After a section has been rough stripped, it is gone over again, carefully cutting to the bottom of the good soil and working from the back of the cut. The windrows of topsoil left by the sides of the blade are then pushed in. If two dozers are working, the one with the more accurate blade control, or the smaller one, is used for the cleanup.

Careful separation of the topsoil from subsoil is a requirement of most stripping. Inclusion of even considerable amounts of loose fill in topsoil does not usually damage its usefulness, but it is a type of adulteration that is unpopular with the buyer. The damage to appearance and value is especially severe if the subsoil is a conspicuously different color, or texture, or is in the form of lumps or sheets. It is generally better to leave a thin sheet of topsoil on the field than to mix topsoil and fill.

However, if the stripping is done in order to get clean dirt or gravel for roads or other purposes, it may be better to concentrate on cleaning the surface, even if some fill mixes with the topsoil.

Topsoil and subsoil are separated chiefly on the basis of color. If the difference is prominent, the distinction is easy to make, but the results of a mistake are painfully obvious.

Light conditions may obscure the color difference. When the sun is very low, in the morning or evening, or high in a clear sky, subsoil and topsoil may look the same. Cloudy days and intermediate sun elevations give the clearest distinction.

Any shovel rig can be used for piling topsoil. The skimmer and dragline are best at it, and the toothed clamshell slowest. Shovels work rather slowly in shallow soil. The hoe is adept at salvaging soil along a wall or fence.

Shovels loosen and aerate the soil, and cause minimum damage in handling it when wet. Fill dug with the topsoil can be concealed by mixing in. Teeth prevent abso-

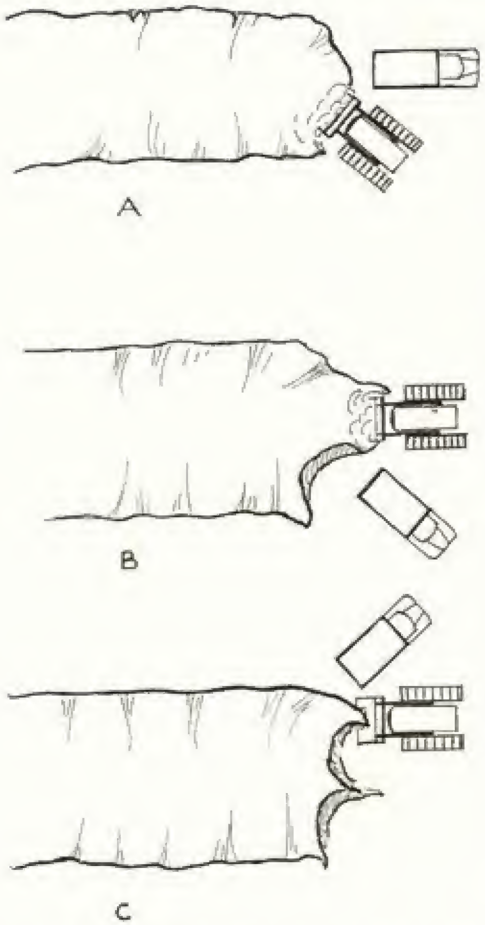


Fig. 10-14. Loading topsoil with shovel dozer

lute accurate work, and it is good practice to clean up afterward with a dozer.

Scrapers are used for piling topsoil chiefly when it has to be completely removed from a large work area. They generally make wide, low piles that are more readily rehandled by scrapers than by other excavators. They pack the soil heavily even when it is in good working condition.

If topsoil is stripped from one part of the job at the same time that it is spread on another, the scraper can combine the two operations very efficiently.

Scrapers drawn by fast wheel tractors may be used to dig topsoil and deliver it by road to local customers, who will appreciate having it spread.

Loading from the Pile. Topsoil is comparatively light and normally has a low digging resistance. However, it tends to push ahead of narrow buckets, instead of entering them, and this factor, coupled with the small size of the usual pile, may reduce production below that of hard digging in a bank.

Difficulty in filling the bucket may be reduced by thorough chopping of sod and weeds before piling, building large piles, and building piles on undug areas so that the bottom of the bucket will work in firm soil.

The best machine for topsoil loading is the chain bucket loader. Its feeding mechanism chops up sod and trash, and mixes, aerates, and puffs up the bulk of the soil. Although production rate is usually high, the soil is discharged in a thin stream, so that trash and rocks are readily removed.

It can dig directly from an unplowed field but output is higher in piles. It is seriously hindered and may be damaged by large rocks or roots.

Next in preference is the shovel dozer because of flexibility, ability to load from either pile or field, to clean up as it works, to pile when not loading, and high production in relation to purchase price. Trucks are backed into the end of the pile, in variable positions to keep them at an angle of about forty-five degrees to the digging, as shown in Figure 10-14. These wide buckets get heaping loads until the end of the pile is reached. The remnants can be pushed to the next pile.

The dipper shovel is widely used. It may have trouble filling the bucket but its principal difficulty is in cleaning up. If the pile is narrow, as in Figure 10-15 (A), it can walk down the center and scrape in the sides by swing dragging. If the pile is heavy, as in (B), it can dig the bulk from one side, easily cleaning as it goes, and come back through the small remnant. In either case, it is best to have a bulldozer

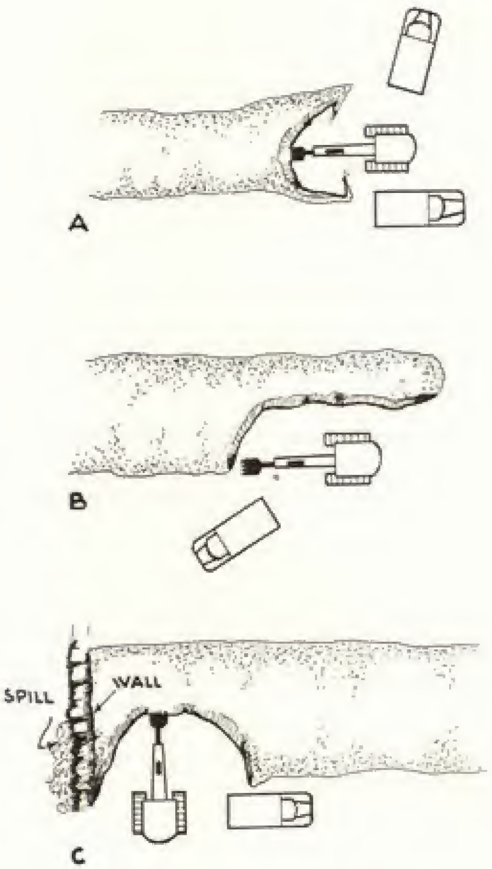


Fig. 10-15. Loading topsoil with dipper shovel

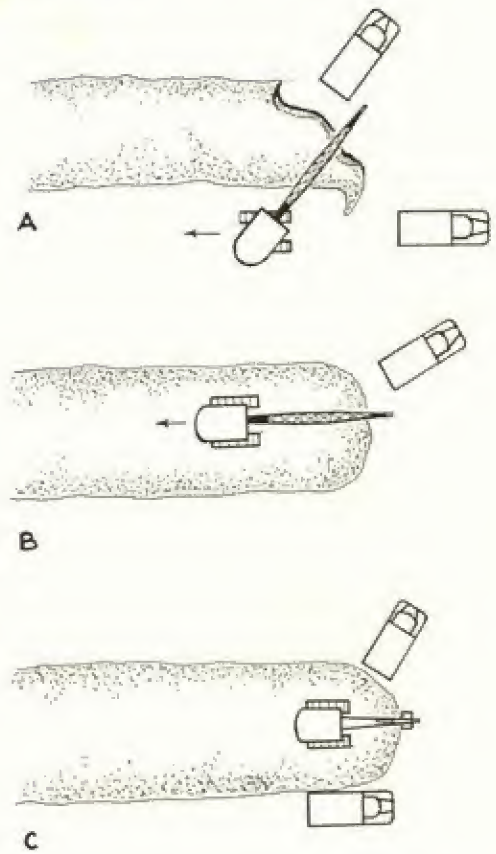


Fig. 10-16. Loading topsoil with dragline and hoe

work with it, at least part time, cleaning up. A light rubber-tired dozer is generally adequate.

When digging a windrow ending in a wall or property line, as in (C), the shovel should be started at that end and worked in, to minimize working soil over the end and losing it.

Draglines and clamshells can be worked from one side of the pile, as in Figure 10-16 (A), or preferably from the smoothed-off top, as in (B). The top of the pile is particularly suitable for hoes, as in (C), as they load more rapidly and easily if higher than the trucks. These rigs clean up the edges without extra work but can strip closer if aided by a dozer.

Any shovel cutting to a grade will occasionally go below it so that fill will be dug. The mistake is immediately shown by the color of the bottom. The bucket should be dumped off to the side to be wasted, or on the pile, to break up and mix the slice of fill. Subsoil may be deliberately dug and mixed in this manner if the topsoil is rich and the price is low or the buyer indifferent.

If the soil is uneven in quality, the shovel may mix it up during loading.

The buyer may not be able to judge the quality of the topsoil he is getting from observation of it in the truck, or after being dumped. The operator of a revolving shovel may put undesirable material in the back of the truck, good soil in the front and over the top. The top layer is all that is seen in

transit and that which was in the bottom front after it is dumped.

If any doubt exists about the reliability of the supplier, the loads should be spread as soon as received.

Loading from the Field. Topsoil is often loaded direct from the field, with no systematic preliminary piling. The efficiency of the operation depends on the depth of the soil, the machinery used, and the output required.

Best results will be attained in deep soils, as increase in depth reduces the proportion of time spent in trimming the bottom and in moving into the digging.

Unless the soil is very hard or rocky, the bucket loader gives the best results; particularly as vegetation does not have to be disked ahead of it. The dozer shovel and the skimmer are well adapted, and practically any loading machine can be used unless the soil is quite shallow.

High production cannot be expected of any machine, except possibly the bucket loader, in shallow stripping. However, if the trucks are scheduled so that the shovel dozer has free time between them, it can stockpile enough to enable it to fill the truck quickly.

Sometimes a bulldozer is used to boost output by feeding soil to the loader. This may be done on the whole job or just on thin spots. Dozer cleanup after digging is usually desirable.

Screening. Topsoil may be coarsely screened on a portable grizzly, which is placed on the truck body prior to loading, or may be up on legs so that the truck can back under it. The latter type requires large piles for convenient use. A truck with a permanently mounted screen can be used to haul to a nearby stockpile.

These are used either to market topsoil which is otherwise unsalable because of presence of rocks, roots, and trash; or to obtain a premium price. It is usually necessary to have a man to clean stuck material off the grizzly. Best results are obtained with dry or sandy soils. Heavy soils require a coarse mesh and must be put on a small quantity at a time, or too large a proportion may be rejected.

Reducing the slope of the screen will allow more material to go through, but will increase sticking and piling up on the surface.

Square openings from one half inch up to four inches are used, or similar bar spacings.

A much finer product, with less waste in rejections, can be obtained by using a revolving screen on the discharge of a bucket loader. A portable gravel screening plant might be used, with some changes.

If the topsoil is full of lumps, a hammer mill shredder may be used to reduce them.

If only occasional loads are required, hand screening will be more economical than the purchase or conversion of equipment.

Artificial Topsoil. Topsoil of fair to excellent quality can be manufactured by expert mixing of fill and peat (humus). Poor quality topsoil can be enriched, or dark rich soil made to go further, by similar mixing.

If the humus is pure (less than 20 percent ash when burned after drying), and air dry so as to contain less than 25 percent water, about one part of humus to two to four of fill is used. The fill should be of light texture, but not coarse or gravelly, and preferably taken from near the surface. Fine white sand is sometimes used instead of fill, to provide a mixture for topping golf greens.

The mixing is done by a bucket loader. The two materials may be fed to it from stockpiles by a dozer or shovel, or a combined pile may be made by dumping and leveling fill, and then dumping humus on top to make proper proportions.

Revolving shovels can mix the materials by piling and re-piling.

Peat is generally quite acid, and unless an acid soil is wanted, or the fill is quite alkaline, ground limestone should be added at the mixing paddles. Manure, or general purpose chemical fertilizer, such as 5-10-5, added at the same time, will improve the product.

Success in topsoil compounding depends on a supply of good cheap humus and suitable subsoil, proper fixing, and local acceptance of the product.

Storage. Topsoil is often left piled for long periods. Texture is generally improved by standing over the winter, and quality does not seem to be damaged much even by years of storage. In hot dry seasons, it may bake out to colorless dust, which is unpleasant to load and hard to sell, but a wet season will restore its original texture.

However, piled topsoil will support a luxuriant growth of grass and weeds, which quickly forms a sod that is very undesirable. The irregular shape of the piles makes cultivation with any ordinary tools almost impossible. Flame guns are tedious to use and ineffective, and chemical weed killers are selective and uncertain in action.

Such growth can be kept down, at a price, by cultivation with a bulldozer, as in Figure 10-17. The machine is run along the crown of the windrow, cutting off the top and allowing the dirt to flow down the sides. This uproots or buries a large part of the weeds. Later the bulldozer pushes the sides back up to the top, as in (C) and (D), destroying the rest of them. Most economical results are obtained by allowing a week or more to pass between the two operations. The job is done over as often as necessary.

This serves not only to keep the soil clean, but also to enrich it by the decay of the weeds.

Restoring Vegetation. When topsoil stripping is not followed by other work, areas are left denuded of vegetation and

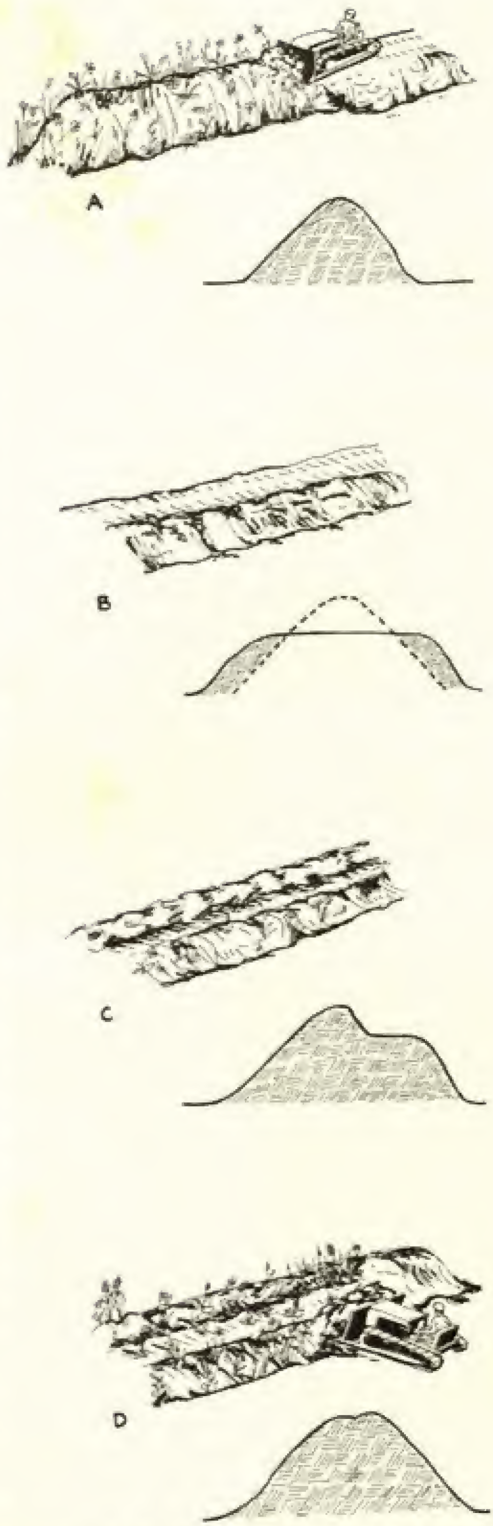


Fig. 10-17. Weed control on piled topsoil

the ability to grow it. They tend to cause a dust nuisance, and to erode badly, becoming a mass of unsightly gullies, and often silt up streams and block roads with the waste.

As a result of such nuisances, many communities now forbid the stripping of topsoil, or impose restrictions on the work. The least of these is to require a guarantee to restore the vegetation on the stripped areas.

Under favorable conditions, this work is neither difficult nor impossibly expensive, particularly if some topsoil is left.

The process is similar to that required to restore worn out and eroded farmland. The ground is loosened with rippers and plows, loose rocks are picked up or pushed off, a liberal application of manure or fertilizer and perhaps of lime made, and a crop planted. Fertilizing and seeding should be heaviest in drainage ways. This crop should be one that will grow readily on poor land. The local Farm Bureau will be able to advise one or more suitable for the conditions and season.

In many localities, buckwheat or soy beans make a good summer crop, and a rye and vetch mixture is suitable for fall or early spring. When the plants are in flower or beginning to seed, they should be plowed or disked under, and additional fertilizer supplied to spots that did not grow properly. After an interval of two or more weeks, depending on local practice, another crop, preferably a self-seeding legume such as sweet clover, is planted. The seed should be inoculated with a culture of the proper nitrogen-fixing bacteria. Some patch fertilization and replanting may be necessary later, and any tendency to gully can be checked with topsoil patches, heavy fertilizing and planting, or brush mats.

With luck and good farming, the second crop may hold the land so that no further plantings are necessary. Decay of plants and nitrogen absorbed from the air will enrich the soil, so that the native vegetation of the area will soon be able to reestablish itself.

Reclamation probably gives best results on glacial till soils which will develop a new topsoil cover in a surprisingly short time. The author has taken good topsoil off land that was thoroughly stripped ten years before. In this case, however, three or more crops were turned under before sweet clover was left as a permanent cover.

Floors of deep pits will respond to the same methods but much more slowly. Deep subsoils rarely have proper tilth, or plant food in quickly available form for crops, so more "green manuring," or turning under of vegetation, is required.

Animal manure will give better results than chemical fertilizers, particularly on floors of deep excavations, largely because it contains many organisms essential to a healthy soil. However, in many localities it is difficult and expensive to obtain.

It is advantageous to plant as soon after stripping as possible. If an interval is to elapse between piling and loading, it is good practice to plant a cover crop between the piles to prevent the development of a dust nuisance and loss of topsoil remnants.

PEAT (HUMUS)

Characteristics. This is a light, soft, absorbent, organic substance formed by partial decay of vegetation, which accumulates in more or less pure form in swamps or shallow ponds. It is usually brown or black, and may be a structureless jelly, or fibrous, or lumpy with recognizable remnants of wood or leaves.

It may be mixed with varying quantities of soil which increase its weight and will make it lighter in color, particularly when dry. Water content is 50 percent or more by volume.

When pure from 70 to 85 percent of its dry weight is organic and the balance mineral ash.

In some countries it is used extensively as fuel, when partly or wholly dried.

If allowed to dry in stockpiles or dewatered deposits, it will take fire rather easily and burn slowly and persistently. It can be put out by complete soaking, or controlled by cutoff trenches. This problem is discussed in Chapter 1.

Peat is usually very acid. It may contain no immediately available plant food, but reserve supplies in insoluble form are good, particularly of nitrogen. It may be sterile, or able to support only limited growth, when first dug, but on exposure to weather it will gradually become fertile. It will make good topsoil when mixed with soil or sand, and lime and manure.

It is used to enrich lawns and gardens and occasionally farms. Golf courses use large quantities. It will soften heavy soils so that they will not bake hard; and make light soils absorbent so that they will not dry out readily. Use of large quantities at one application, particularly without thorough mixing, may unbalance the soil so as to make it temporarily unsuitable for some crops. Lime should be used liberally with it unless acid loving plants are to be grown. Manure, or to a less extent fertilizers, may prevent unbalance.

Humus may be tested for water content, for organic matter, and acidity. A quantity is weighed, baked dry at low heat, and weighed again. The difference is the water which it held.

The dry humus is then raised to a red heat, stirred occasionally, and kept at this temperature until it has been reduced to ash. The ash is weighed. The difference from dry weight is the organic content.

Confusion is caused by the use of humus and organic content in reference both to the total weight of dry plant or animal remnants, and the non-ash part of such remnants. As an example, a pure peat deposit may be said to be 100 percent humus or organic material; or 85 percent humus after allowing for the minerals contained in the woody fiber. Both usages are permissible.

Percentage tests are best performed in the laboratory but they can be done roughly in the field, or at home, with a heavy pot and kitchen or parcel post scales. The pot should be weighed separately, and all other weights taken in it. The largest quantity convenient should be processed to minimize errors in reading the small weight of the ash.

Burning humus may produce noxious fumes so good ventilation should be provided.

Tests for acidity are the same as used for topsoil. Extremely acid conditions are to be expected.

Digging. Peat is normally a water level or underwater deposit. It is often readily drained or pumped dry, and is soft and light to dig. However, it is difficult to recover, particularly in large deposits, as it is sometimes too unsubstantial to make safe footing even for crawler draglines on platforms, or to support ordinary haul roads.

Methods of digging and getting it out of the pit are discussed in Chapters 3 and 6. In general, the cable excavator mines it at lowest overall cost, and with fewest complications, but operations are often too small to justify the necessary investment.

Curing. A particular problem is the high water content. Half to three quarters of the water will drain out of a pile in a month or two of dry weather, reducing its bulk 50 per cent or more. The balance will stay in it unless baked out, and is a normal part of bulk or screened humus.

Before draining, the humus is too wet for handling as it becomes sloppier each time it is moved, and it will not respond to processing. Provision must therefore be made for curing between the pit and the plant or customer, unless the plant is equipped with drying apparatus.

A drag scraper or slackline may dump

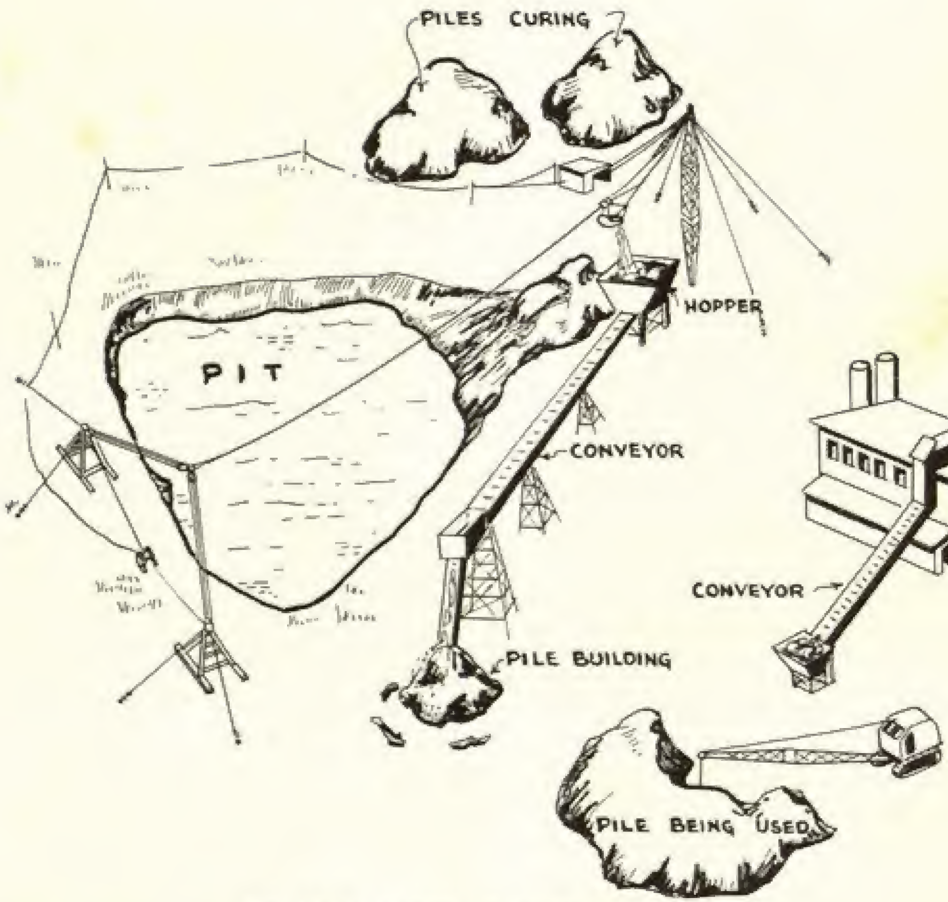


Fig. 10-18. Humus pit layout (scale distorted)

into a hopper, from which one or more movable conveyors carry it to piles, as in Figure 10-18. The conveyors may have to use cleated belts, or buckets, to prevent the peat from flowing back along them. Conveyors, loaded by dragline or clamshell, can reclaim the piles to the plant; or the material may be loaded into trucks for sale as "raw" humus as soon as it has drained.

Draglines may pile it up at the pit edge and return to load it.

Machines handling dry or partly dried humus can be equipped with oversize buckets, or oversize drum lagging, or be run in a higher gear than it can when handling heavier soils.

Processing. Humus is processed to break up lumps, to mix together different colors or grades, to mix in soil accidentally or deliberately added, and to increase bulk by fluffing and aerating.

A bucket loader will usually perform these functions, except the first, and load into trucks or storage at the same time. If lumps are soft, it can break them as well, and if they are hard but infrequent, they can be removed by a man stationed at the discharge. If the ground under the pile is too soft to support the loader, it can walk on saplings or planks placed behind the blade and ahead of the tracks; or it can stand on firm ground and be supplied by a shovel.

Humus loaded in this manner may or may not pass as a screened product.

When lumps are a serious problem, or the product must meet rigid specifications,

a shredder, often a special type of high speed hammermill, is used. It is lighter and less costly than rock crushing models, but operates in the same way. Toothed drums may also be used.

In small operations, the shredder may be supplied with hand shovels, and the product hand shoveled into trucks or left in a windrow to be gathered by a loader.

A portable conveyor belt may take the humus from the discharge opening and load it in trucks, or on a pile. Larger portable mills may have a high hopper opening supplied by a hand loaded conveyor belt.

The shredder can also be fed mechanically by any kind of loader, without hand work.

Portable crushing and gravel plants are sometimes successfully adapted to processing humus.

Fixed plants should be on firm ground outside the pit, and may be supplied by cable excavator, conveyors, or trucks. They are capable of much higher production, and may turn out a finer or more uniform product. They can be equipped with drying and packaging machinery so that their product can be sold in stores.

In any calculation about humus it should be remembered that one yard in the wet deposit or pile means a half yard or less in the cured pile.

GRAVEL, SAND AND CLAY

Bank Gravel. Bank gravel is a useful and highly varied material. It consists chiefly of sand, pebbles, and cobbles, but may also contain clay, silt, and boulders, mixed in or in accompanying layers or pockets. The gravel proper is the pebbles and cobbles in sizes from ¼″ to 2″.

The specifications which gravel must meet to do certain jobs, and the proportions found in deposits, vary widely. The range of road gravel requirements is indicated in Chapter 8.

Bank gravels consist mainly of deposits laid down by fast running streams, often of glacial origin, but they are also formed by waves on the seashore. The quality depends not only on the proportion of sizes but also on the angularity of the particles. Wave formed gravels are predominantly rounded, glacial ones subangular, and product of other streams variable.

Talus gravels, formed at the foot of cliffs by falling and sliding pieces of rock, are usually very coarse and angular.

If gravels are not sufficiently angular for their job, and contain oversize stones, they may be run through a crusher which will produce angular fragments.

Fines in bank gravel act as a cement or binder, holding it together when dry. Gravel without binder becomes too loose for road use in hot, dry weather.

Fines in excess of eight or ten percent may cause a gravel to become sloppy after repeated freezing and thawing when wet. Fines over fifteen percent may cause it to soften under prolonged soaking. Softening is made more likely by a high proportion of fine sand in the mixture, and less likely if thorough compaction precedes the freezing or soaking.

Any gravel will become sloppy if soaked when freshly dug, but if of good quality, should drain and firm quite quickly.

Gravels derived from continental glaciers are largely of hard rock. River and mountain glacier gravels are derived from upstream formations, and occasionally include too much shale or other soft rock for some purposes.

There are a number of tests for gravel, for field and laboratory use.

If a specimen is rolled between the fingers, it will separate into grains which, if inspected with a magnifying glass, will indicate something of the sharpness and assortment of the sand particles.

A sample, with stones over one quarter inch removed, can be shaken up with water in a glass jar, then allowed to stand. The

pebbles will form a layer in the bottom, with coarse and then fine sand on top. Silt and clay will settle out more slowly, and may take an additional day to compact. The relative amounts of the different size particles can then be determined by inspection.

In the laboratory, gravel is dried, weighed, and put through a vibrating screen with many different meshes. The particles caught on each tray are weighed. Any lumps have to be broken up. This operation gives a classification of the specimen for size gradation.

Gravel can be tested for abrasion resistance by rolling in a cylinder with steel balls or other hard weights. Resistance to breaking up by freezing can be tested with cold, or with chemicals which duplicate its effect.

Clean bank gravel of proper sand-gravel proportions is frequently mixed directly with cement for concrete.

Sand. Most bank gravel deposits are more than half sand. In addition sand deposits occur over areas where no gravel is found.

Ocean beaches are typically sand, and river deposits usually contain high proportions of it. If the river flows slowly, the sand may be mixed with silt and clay, which usually must be separated before use.

Most sand is largely particles of silicon dioxide, best known in the form of quartz. It is very hard and withstands the abrasion of water working which reduces other minerals occurring with it to fines. Calcium carbonate, mica, feldspar, gypsum, and many other minerals may also occur as sand.

Many sand banks are clean enough for use without processing, but in most cases it is safer to screen and wash before using in concrete.

Occurrence. Sand and gravel deposits occur in all parts of the world, and with special frequency on or near past or present shores, glaciers, and mountains. They may be thin, irregular deposits, or in heavy masses. In general, gravel is more variable than sand in size and type of particles, and thickness and shape of beds.

Running water needs higher velocity to carry large pieces than small, and in general, gravel is deposited nearer the source than sand, or at times of heavier stream flow. However, a stream which is building up a deposit, alternates bringing in materials and cutting parts of it away. Channels wander over the whole area. Oversize material beyond the capacity of the water to carry may be rolled long distances along the bottom. Clay and silt may be deposited in temporary pools and cut off and stagnant channels.

The result of these factors is that gravel, sand, and clay deposits are often extremely variable and uncertain. When this is the case, mining them requires constant good judgment in deciding which horizons should be combined and which separated; and what can be used and what must be wasted.

Processing. Sand and gravel may be processed to clean out dirt; to separate into different sizes; to combine different sizes and materials; to remove or crush oversize stones; and for combinations of these purposes.

In variable formations, the primary processing is selection at the bank as discussed under selective digging.

The processing plant proper may consist of a washer, a screen, a crusher, or multiples or combinations of these units, together with feed hopper, and transfer and discharge conveyors. These plants, available in both mobile and portable types, are described in Chapter 21.

By the use of units of proper size, any desired reduction, combination, or separation can be secured. It should be remembered, however, that no plant can produce a coarse product from fine particles. Deficiencies in gravel content must be made

up by mixing in stone of proper size, or oversize up to the crusher capacity, in addition to the run-of-pit material.

Clay. Clay, like sand and gravel, may be found in massive deposits or in irregular layers and lenses. It is often interbedded or mixed with other materials in very complex ways.

Underwater clay may be soft enough to be dug with a small dragline, or quite hard. Dry clay grades from hard shovel digging to shales requiring heavy blasting.

Pit operators usually find it economical to loosen up dry clay with at least light blasting, to facilitate digging. Electric or gasoline driven augers are extensively used for drilling, and slow to standard dynamites for blasting.

When valuable clay is in narrow and confused beds it is often blasted, then separated by hand into piles which are loaded by machine.

LOADING OUT OF THE BANK

Most primary pit excavation is in formations deep enough to be loaded directly from the bank. The material may be in its natural state or loosened by blasting.

Bank Height. In free flowing material, such as loose dry sand, the only limit to bank height is that imposed by safety. This will be discussed below.

If a formation will stand in vertical or overhanging walls, and is dug from the bottom, the face should not be higher than the machine can reach. Half this height will usually be more convenient and give better production. For example, dipper shovels of two and a half yard capacity seem to do best when the bank is between twelve and fifteen feet high.

Lower faces require more frequent moves. Higher ones require the bucket to travel farther with resultant loss of time.

Types of Machinery. Loading machinery used for pit excavation can be roughly divided into tractor loaders, which depend on traction on the pit floor for digging power; revolving shovels with dipper, clamshell, or skimmer front ends, which stand on the floor while working; revolving shovels, with dragline, hoe, or clamshell rigs, which load from the top of the bank; scrapers and bulldozers which work down the bank slope; and remote control cableway excavators.

Selection of machinery will depend on the location and digging characteristics of the formations, the volume of output required, the type and importance of other work that must be done by the same machines, the type of haulage or conveyor units, and the price tags.

Production Factors. Big machines are suited to hard and coarse formation and to high production requirements.

Practically all excavators are available in different sizes. Production usually does not increase in direct proportion to power and weight, as the more massive construction of heavier units may require lower speeds, and space may be lacking for convenient operation.

Manufacturers' data on output should not be accepted without careful study. Some firms deliberately underestimate production to avoid arguments; while others exaggerate it to make sales. Others base it on time-motion calculations, with little reference to field conditions.

Production ratings based on loose yards, or on a sixty minute hour, will be higher than for bank yards, or a fifty minute hour.

Also, there is room for honest difference of opinion about whether a formation is hard or soft, and conditions average or ideal.

A rough index to output can be obtained by timing a machine at work in various materials. A stopwatch should be used and the results written down. The cycle time is the elapsed time between a certain movement, as entering the bank, and the repe-

tition of that movement. Average number of cycles per minute, from a number of observations, multiplied by the average bucket load in yards, will give the production rate in yards per minute in simple work such as sidecasting. Extra passes made to trim the bottom, or to break out or avoid boulders, may be averaged in or considered separately.

If the machine is loading, the loss of time in spotting trucks and trimming up their loads should be observed.

Data for calculating production are included in Chapter 3.

The figures obtained must be modified to allow for mechanical difficulties, maintenance, cigarette time, failure of trucks to keep up their schedule, blinding dust, and inspection of bank material. These are often lumped together as one-sixth of operating time, so that each hour is figured to have only fifty working minutes. If the calculation is to determine the number of days required to do a job, weather must be allowed for. This will include the time the job is shut down because of rain and resulting mud.

Big machines can almost always dig hard material better than small ones of the same type, but this factor is even harder to calculate. A rough index to penetration in material of even texture can be obtained by dividing the force which can be applied to the bucket by the width of the edge, or the combined width of the teeth. The extra resistance to the thicker teeth of the heavy bucket may be negligible in brittle formations and important in resilient ones.

In poorly blasted rock, or boulder-filled banks, the gain in penetration is much greater, as nearly the full power is often applied in succession to points of greatest resistance.

A wide bucket may be at a disadvantage because of inability to get between obstacles to attack them separately, or benefit from its capacity for large chunks.

In any digging, sharp cutting edges are essential to best work. In hard formations, teeth of proper spacing will give better results than straight edges.

Mobility is an important factor for machines which may dig for short periods from a number of different bank sections, or are used for loading from storage piles as well. Ability to do several types of work is liable to be useful, particularly in small pits.

It is good practice, although not always essential, to match the size of loading and hauling units. If large shovels are used with small trucks, time is wasted centering the bucket and material will be spilled off the sides. Truck tailgates may be jammed by oversize pieces and trucks damaged by impact. If the trucks are too large for the shovel, they must spend too much time being loaded; the shovel may be unable to fill them from one stand, and high body walls may hamper it.

Revolving shovels are usually teamed with trucks which will carry between five and ten bucket loads. Capacity is not as important for tractor-loaders but body walls should be low enough to permit easy placement.

Tractor Loader. Tractor loaders include crawler types, which can do moderately hard digging and heavy bulldozing, and units on rubber tired wheels, which generally will dig only soft or loose material, and should operate on hard ground. The wheel units have smaller buckets for their power and weight and are usually cheaper to buy and to maintain.

Crawler mounted loaders are easy enough to move around pits of moderate size, but the wheel mountings are superior in speed and cause less wear to themselves and to the roads while traveling.

Four wheel drive loaders have digging power intermediate between the two types and have the mobility of the wheel mountings.

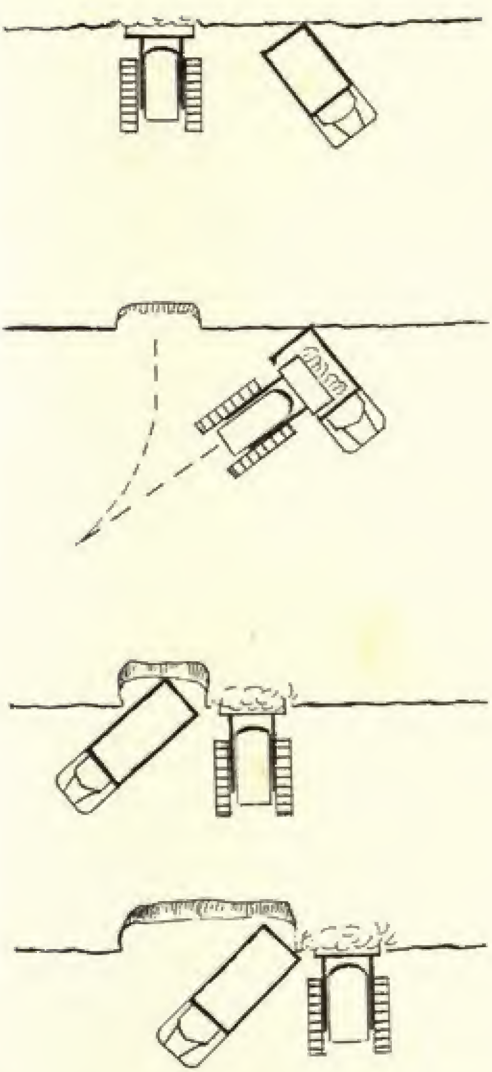


Fig. 10-19. Loading from bank with shovel dozer

Three types of bucket are used: the hydraulic dump, the gravity dump, and the overhead. Hydraulic dump is much superior to gravity for most uses and is slightly more costly.

A good pattern digging with a dump bucket is shown in Figure 10-19. While these machines are flexible and can dig under very awkward conditions, best production is obtained if both angle of turn and walking distance are kept to a minimum. Best height for non-caving banks is about level with the push arm hinges.

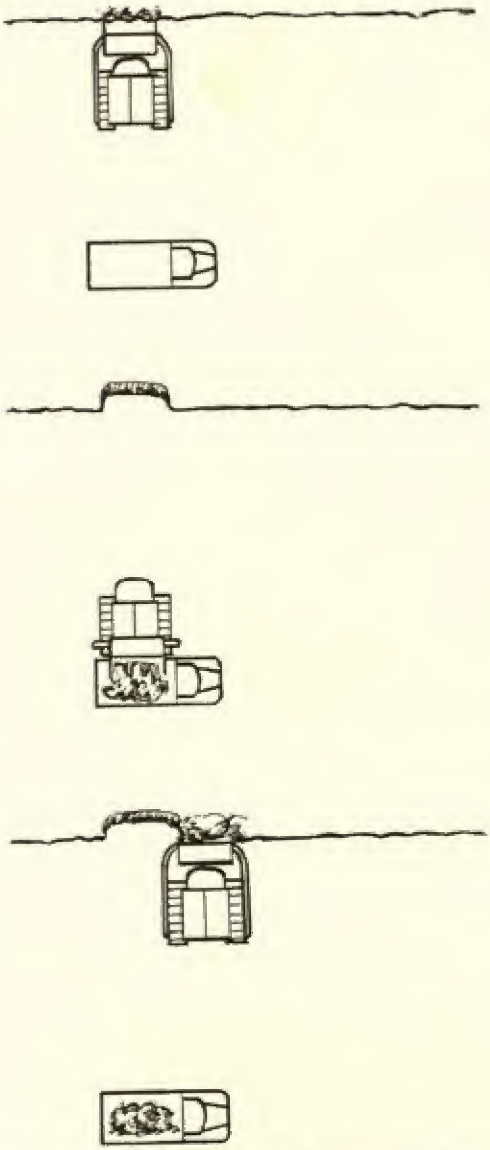


Fig. 10-20. Loading from bank with overhead shovel

Hydraulic dump buckets, when full tractor width, can be used as bulldozer blades without any lost time for changeover. Teeth, if used, are generally not long enough to interfere seriously with grading work.

The overhead or overshot shovel operates best in a shuttle pattern, as in Figure 10-20. This machine generally obtains higher production, with less wear, than the turn-and-dump types. It is easier to use

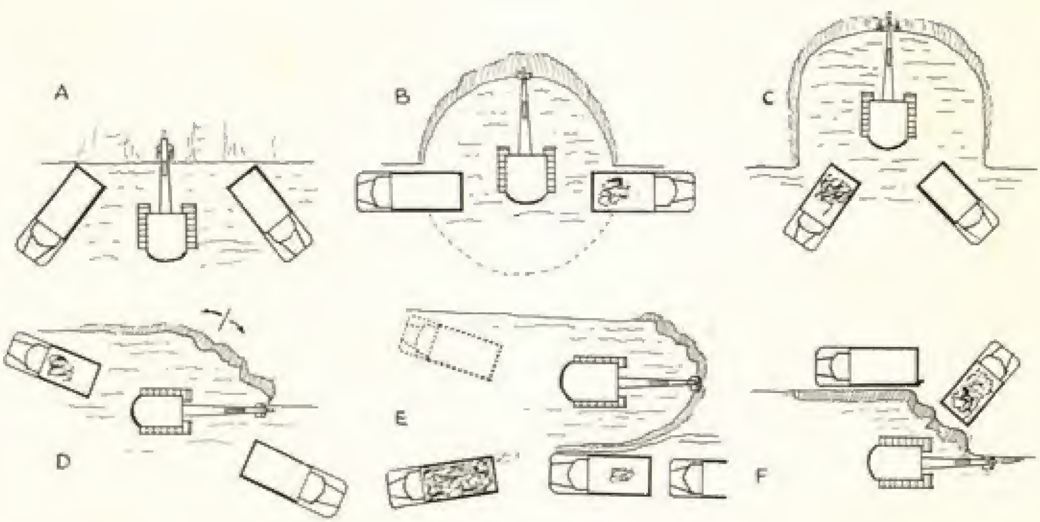


Fig. 10-21. Loading from bank with dipper shovel

in soft pits that will be kicked up by turning, and on which trucks have to be kept in certain paths. However, it is not as flexible as the other type and can be used as a dozer only with a full bucket, or after replacing the bucket front with a blade.

Any tractor shovels can be conveniently used as prime movers for shifting heavy machinery and for starting or rescuing trucks. They are also handy for hoisting and carrying.

Dipper Shovels. The dipper shovel is the standard tool for bank excavation. Although fastest loading is in soft material that will heap on the bucket, they can maintain good output in very hard or rough material. They are more costly in proportion to capacity than the tractor loaders, but have lower repair requirements as the tracks do not move during the digging cycle.

In the smallest sizes, and when mounted on wheels in any size, they have good mobility. Medium and large sizes are generally not moved around for less than a day's work.

They will dig from any graded floor that will support trucks. Best production in noncaving material is usually obtained when the bank is about as high as the shipper shaft (dipper stick hinge).

A short arc of swing is important in getting maximum production. The bucket can usually be moved from break out position at the bank, to correct height and distance for dumping in a truck, during 30° to 45° of swing. Any longer swing required by truck position slows the digging cycle.

When a shovel is walked straight into a wide bank, the initial swing required is about sixty degrees. As the machine works in, the swing becomes longer, finally approaching 180°. See Figure 10-21, (A) to (C).

If the shovel is walked parallel to the bank, as in (D), trucks can be spotted ahead, at a slight angle to the bank, with a minimum swing of about 40° and a maximum of 140°. If trucks are also placed behind, the maximum swing can be reduced somewhat. As long as the shovel is kept slightly outside the toe line of the bank, as shown, it can do its own cleanup. However, production is increased if the shovel operator can dig roughly, depending on another machine to smooth out the floor.

If the shovel is kept deeper in the bank,

as in (E), a ridge will be left near the toe line, reach to load across it will be longer and a dozer will be needed. However, production from each stand will be greater, which in a low bank may be an important factor.

When the pit floor is narrow, sandy, or wet, so that trucks must keep to beaten paths, the arrangement shown in (E) is the most efficient. The shovel works along the toe of the bank and the trucks run parallel to it, a few feet out. Only one truck can be spotted at a time, but it can be put in position much more rapidly than when backed in.

In banks offering a danger of slides, the shovel should be worked straight in, as in (A), so as to be able to back out directly if partly buried. Cuts should be kept shallow by frequent moves to different parts of the face.

When a pit is being deepened to a soft bottom, and only dipper shovels are available, the trucks may be loaded on the higher level, as in (F). However, the cut should not be so deep that the truck body side is as high as the shipper shaft, if waste time through excessive lift and crowd to dump is to be avoided.

Skimmer. The skimmer shovel is not widely used because of lack of flexibility. It is particularly suited to shallow cuts. It easily works to grade and leaves a smooth surface. Methods are similar to those for the dipper type.

Clamshell. The clamshell is so versatile that it is difficult to set up patterns for it. It can stand at the foot of a fairly high bank and dig from the top, or stand on the top and dig from the foot, or can work at any intermediate level. It digs straight down, gathering in its load, without pushing or pulling the surplus. These features make it very valuable in selective digging.

A live boom is required for flexible operation as most digging and dumping are done under the boom point.

The clamshell is adapted to various types of digging by changing buckets or bucket plates. Heavy duty buckets of great weight and reduced capacity will dig very hard dirt and even soft rock. Rehandling buckets are larger, light, and often lack teeth. Medium duty or general purpose models are intermediate in weight and have teeth.

The clamshell has a smaller output than other shovel rigs and is more often used in stock pile, rehandling, and hopper feeding than in primary digging.

Dragline. The dragline is the best machine for loading from the top of the bank if it can dig the material. Small draglines usually are quite helpless in tight or rocky soil, but very large ones will dig almost anything a ripper can penetrate.

Difficulty of penetration increases with depth. For deep work, the boom should be long and digging done well out. This minimizes the upward pull of the drag cable which decreases the effective weight of the bucket.

A dragline can dig harder material from a face than it can cut vertically. If a wide ditch is started by other machinery, it can be continued back into the bank by a dragline. If hard, it will tend to narrow down and become shallow.

The most efficient arrangement for hard digging is that shown in Figure 10-22 (A). The machine works parallel to an existing cut and back from another one. The high wall is cut in the line of walk so that the bucket will not have to try to work down from the surface to keep a wider cut.

(B) is the same pattern except that the bucket is thrown.

(C) is suitable only for easy digging.

A dragline's reach enables it to stand well back from treacherous banks so that it can usually make deep cuts safely.

The dragline loads best if it digs inside the boom point, at a medium depth, with a swing which takes no longer than the raising of the bucket, and the haul units

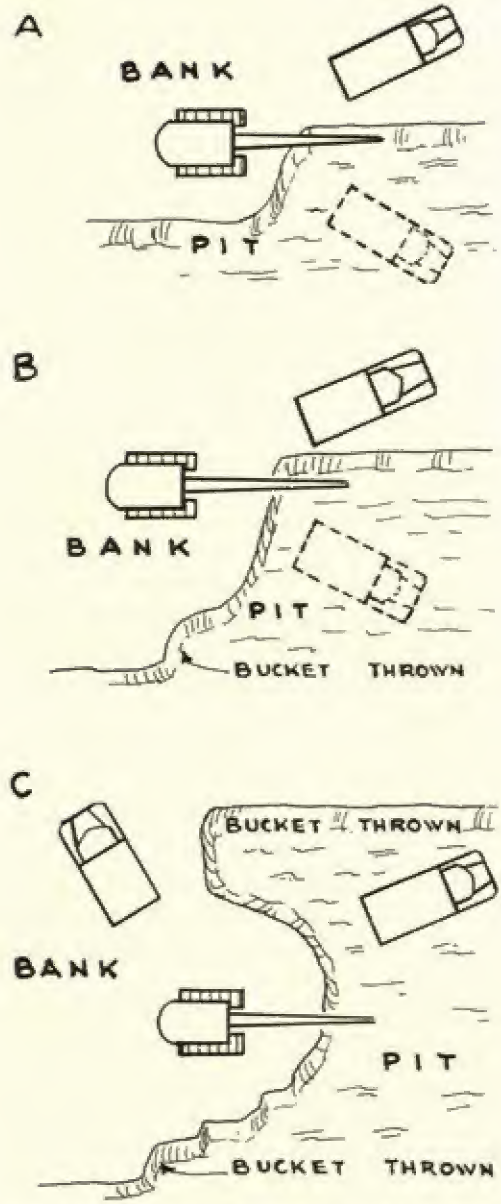


Fig. 10-22. Loading from bank with a dragline

are on the pit floor beside the bucket.

Throwing the bucket may add from ten to fifty percent to the cycle time, since it usually requires that the bucket be pulled in, swung out, then dragged in with a full load until it can be picked up. If digging is done close in, the bucket is simply dropped and raised as soon as it is filled. However, the extra reach is often more important than the time consumed.

Deep digging is slower because of the time required to reel in the additional hoist cable required. At usual hoist line speeds, an extra second is needed for each two and a half to three feet of depth. However, if the swing is long and unobstructed, the time of raising the bucket may not affect the length of digging cycle. If trucks are in the pit, the bucket may be raised only a few feet, regardless of depth.

If the dragline is not overloaded, it should have power enough to perform simultaneously the three functions of raising and braking the bucket, and swinging without lugging down the engine. If the bucket is lifted to dumping position before the swing is completed, it is the length of the swing which determines the loading speed. If the swing is delayed in order to raise the bucket, it is the hojst, and therefore digging depth, which regulates it.

Pull Shovel. The pull shovel or hoe has a shorter reach than the dragline and will dig harder material. It loads more slowly and should be higher than the truck. Height may be obtained by spotting the trucks on the pit floor, while the hoe works on top of the bank or by building up a platform for the shovel.

If loading at its own level, trucks must be brought very close in. The dump is spread over a long strip so that it is most convenient to load the length of the body from the rear. However, there is the danger that a broken cable would allow the bucket to sweep forward and demolish the cab. For this reason, many operators will load only from the side.

Production can often be increased by bigger lagging on the hoist drum, or by reducing the number of parts in the hoist line. A dump bottom or hydraulically controlled bucket will also speed up loading.

Carrying Scrapers. Scrapers are not ordinarily considered to be bank digging

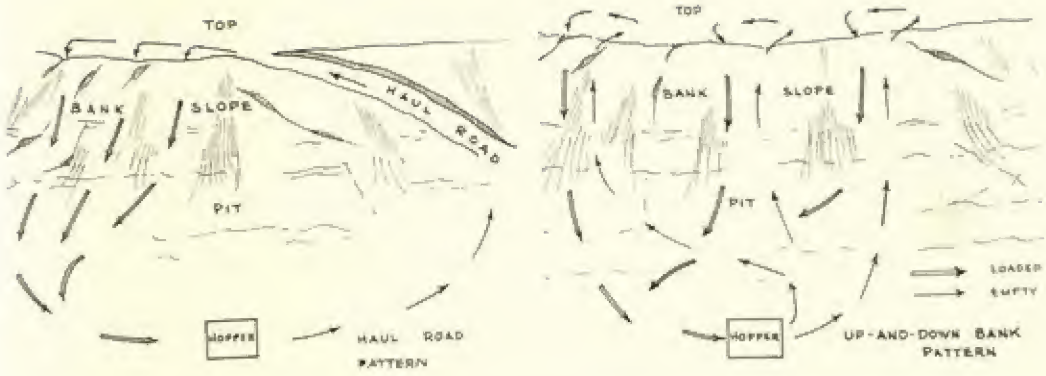


Fig. 10-23. Loading from bank with scrapers

tools, but under proper conditions they may give lowest cost on combined digging and hauling.

The bank is first shaped to a slope that may be between ten and twenty-five percent if the machines are to climb it, and steeper if they reach the top by a haul road. It is desirable that the top of the bank be flat or have only a gentle grade to reduce the danger of tipping while turning. The scrapers are loaded by driving straight down the slope, which should be long enough to give them ample space to fill. Rooters and pushers should be used if required.

The scraper then hauls the load away to dump into a hopper, build a storage pile, or deliver it to a job. On its return, it is driven up the bank, or a haul road, turned on the top and again loaded coming down. The cycle is illustrated in Figure 10-23. Semi-trailer machines may be backed up the slope if turn space is lacking.

Rear dump scrapers are safer to turn on slopes and can conveniently dump into hoppers designed for trucks.

Once the bank is properly sloped, a single scraper may perform all the functions of digging, hauling, and storing without help from other machines or men. Such scrapers can also be used for digging in the pit floor, building haul roads, and grading.

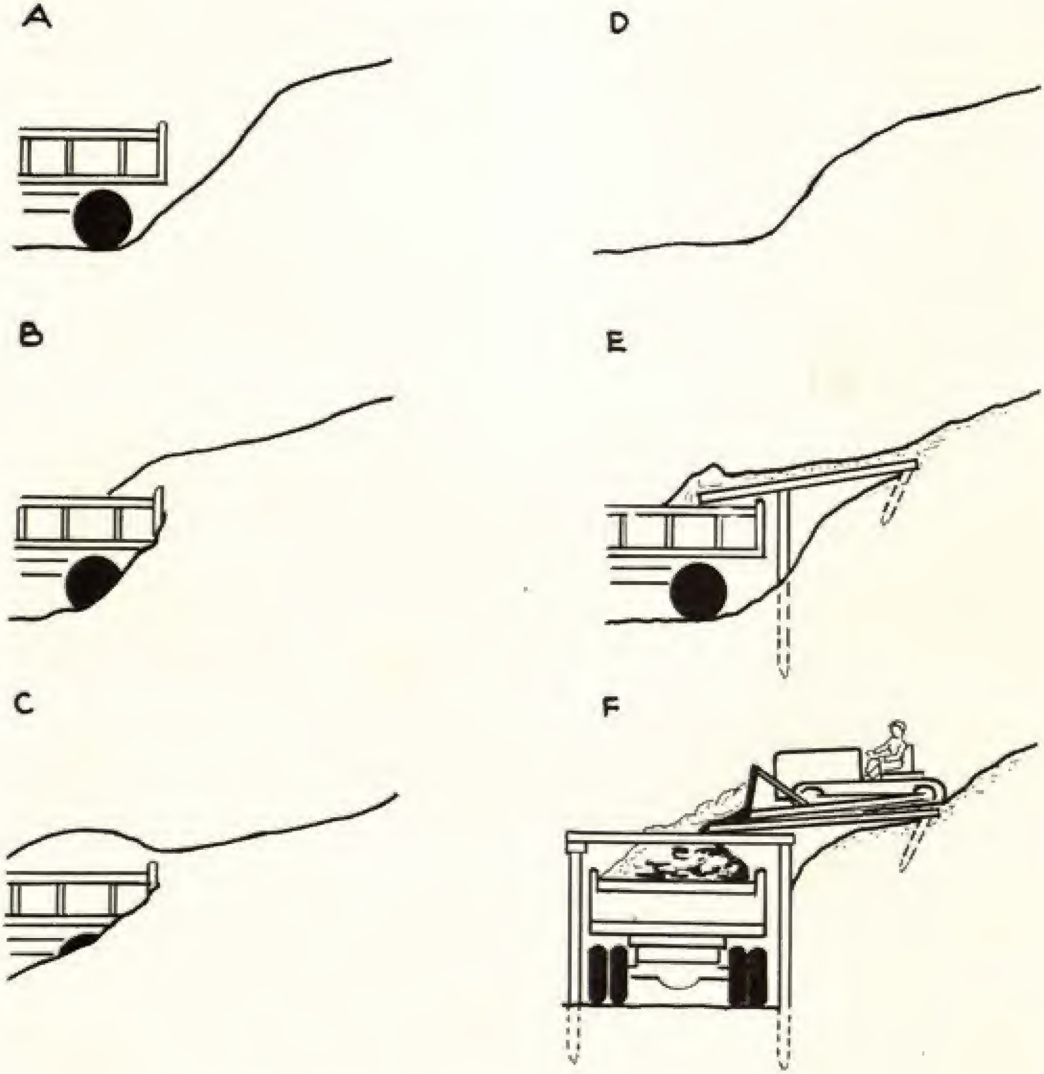


Fig. 10-24. Loading from bank with a bulldozer

Bulldozer. Bulldozers can load trucks from banks high enough to permit the machine to push into or over the body. For occasional loads, this may be done direct from the bank, as in Figure 10-24 (A) to (D). Considerable material is usually lost in building the bank out to the truck, and repeated loading extends the bank out into the pit, requiring a longer push with each load. The truck may get stuck in the spill.

A retaining wall and platform, as in (E) and (F), will eliminate this difficulty. Many other constructions are used. The platform should have steel strips or rails to keep the blade from digging into the timbers. These should be spaced so that the tracks will not have to walk on them. If they are raised above the wood, they will cause a dirt cushion to be built up which will protect the wood from the grousers.

Dozer push loading is most effective in high banks with a slope steep enough to allow pushing of large loads and which will

still allow the tractor to back up easily. Much steeper banks can be used in clay and hardpan than in loose sand or gravel.

Spoil can be pushed in the same manner into a hopper and conveyor, as in Figure 10-25 (A) and (B). When the material within efficient range is exhausted a trench may be made, the hopper moved back into it, and the conveyor extended. Mine-type conveyors with light sections are increasingly used in pits because of the ease with which they can be extended.

Dozer loading from level ground, (C), is not good practice unless material is supplied by scrapers which cannot use the loading trap.

Bulldozers are also used to push bank material within reach of excavators which are stopped by rock outcrops in the toe, and to keep high banks sloped to prevent undermining and caving.

In "glory hole" excavation, which is usually in rock, a tunnel is driven in from the toe and a connecting shaft run to the surface. Rock blasted from the sides of the shaft feed by gravity onto a conveyor, drag scraper, or cars, which haul it out of the tunnel. A bulldozer is not required until the pit has widened its slopes so that rock will no longer slide.

Cable Excavator. These machines are permanent or semi-permanent installations, which should have enough digging within reach to repay the investment. They usually serve as haulage as well as digging equipment.

The drag scraper is the easiest and safest means of digging a high bank which slides or caves. No equipment is needed near the toe, and only the light tail tower and anchors at the crest. If the far side of the crest is accessible, steepness can be reduced as digging progresses.

If the spoil is to be moved a considerable distance across the pit from the toe, a three drum slackline may be used instead of the drag scraper.

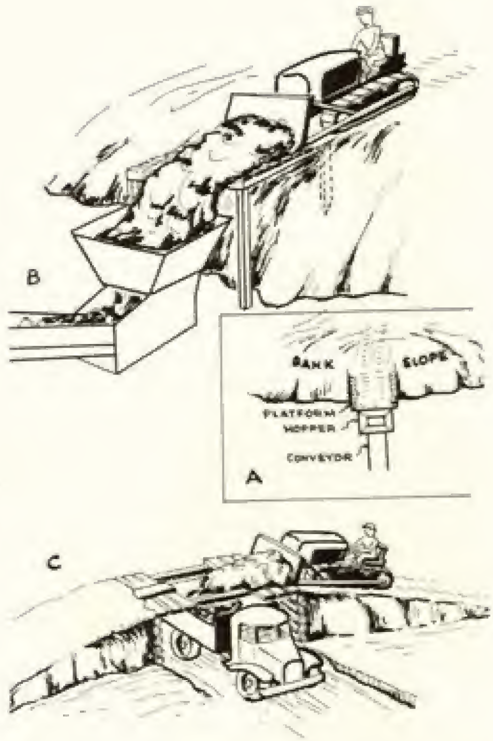


Fig. 10-25. Loading a hopper with a bulldozer

Dumping may be done into the processing plant itself, into a conveyor of any length feeding the plant or through a hopper into trucks.

Digging can also be done on the level and in a pit so that one setting may be used to convert a hill into a hole.

Ability to dig hard deposits increases with size in the same manner as in draglines.

Bank Slides. Most materials will rest temporarily at a steeper slope than their natural angle of repose. Some sand and gravel may stand in vertical or overhanging banks when freshly cut, but eventually fall or slide to slopes between one on one and one on two.

The danger of undercutting high, non-caving banks is obvious. It is less apparent when a bank caves and slides steadily when

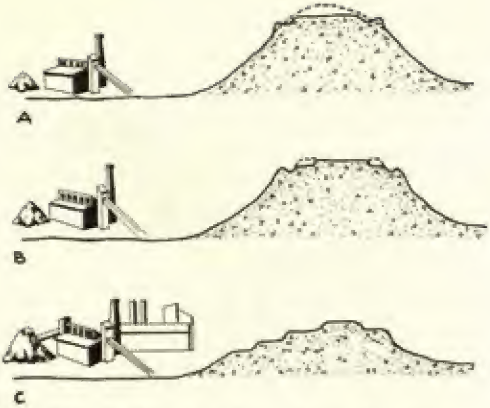


Fig. 10-26. Benching from the top

dug at the bottom, preserving a fairly uniform slope. Such a formation may gradually become too steep to be stable, without giving any indication of its condition. A change in moisture content, a blast, thunder, or the dropping of a pebble may start a slump, which reduces the slope of the face by lowering the crest and advancing the toe into the pit.

The danger from such slides increases rapidly with bank height and its steepness. In many cases, men have been killed and machinery buried in them.

Changes in moisture content affect both internal friction and weight, and either drying out or becoming soaked may create or intensify unbalanced conditions.

Aside from this danger, a high, sliding bank offers best possible dipper loading conditions because of the constant supply of fresh, loose material to the shovel which has to move forward only at long intervals.

Damp clay will usually stand vertically when cut, but will slump or fall eventually. Vibration from passing machinery or nearby drilling is liable to break down its structure so that it will flow. If the movement starts at the top, a dangerous collapse may be caused.

A face of clay or silt exposed to alternate freezing and thawing or internal water pressure may liquefy and flow out on the pit floor, eventually assuming a gradient as low as ten percent. This action is usually too slow to be dangerous, but should be allowed for in figuring clearances for haul roads or in parking machinery.

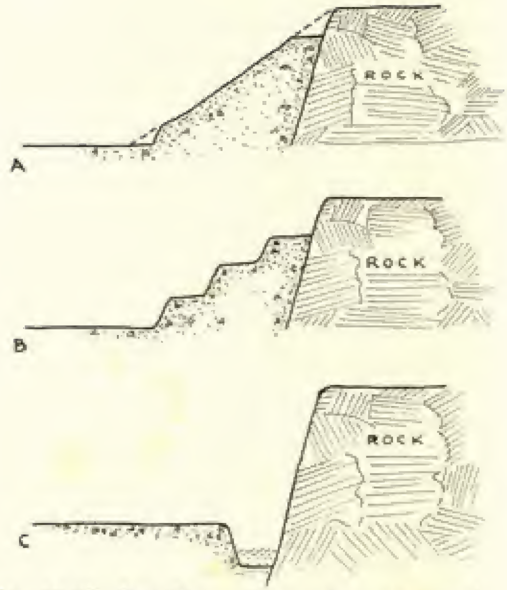


Fig. 10-27. Benching from the top and bottom

High, steep rock walls should be checked for fissures running parallel to the face, which would allow sections to fall off. These are particularly dangerous if filled with dirt that might absorb water and exert a push.

No high face of any kind should be undercut widely without adequate bracing.

The safest way to dig high steep banks in general is with a drag scraper. Sometimes a dragline with a very long light boom, and a backfiller, is used to pull the crest down to the excavators.

On lower slopes, and on firm material, a dozer can be used.

Benching. It is usually good practice to limit the height of shovel cuts by taking the materials in a series of layers or benches.

Two methods of benching a hill slope are described in Chapter 8. Pits are liable to take much larger areas and require many more benches.

Benching may be done from the top down, as in Figure 10-26, or from top and bottom, as in 10-27.

A boundary cut is frequently carried down below the pit floor when the higher parts are exhausted.

A large number of benches may be worked at the same time, or in rotation.

Each bench should be large enough to provide ample space for shovel and trucks. If it is accessible at each end, one way traffic can be maintained and the need for turnaround space avoided. However, narrow roads are often blocked by stalled vehicles, slides, rockfalls, or overbreaks.

If the bench is accessible from only one end, the shovel should work from that end so that the width of the new cut will be available to traffic.

When layers are taken from the top down, starting at a hillcrest, or a back line which will stand steeply, the working area may be made about as wide as desired. The excavating done on the top widens the area available for the next cut.

When cuts are worked up from the bottom, width is largely determined by slope gradient and face height. If the slope is 45°, a foot of height is required for each foot of bench width.

Top benching is preferred for steep slopes whenever immediate access can be had to the top.

LEVEL DIGGING

Material is frequently obtained by sinking the pit floor, or a part of it, in thin layers without developing a bank except at the boundaries of the excavation. The material may be piled before loading, in the same manner as topsoil, but it is usually more convenient to dig directly, with carrying scrapers or cable excavators.

Rooters may be used to loosen the ground for scrapers and for cable excavators except in wet digging.

The wheeled scraper is more flexible in digging, can vary the dumping spot readily, and by change of the number and size of the machines can excavate at almost any rate desired. The machine may also be used in other pit work or outside jobs when the cut is idle.

Under favorable conditions, the cable excavator can dig at less cost per yard. The fact that it is difficult to move is sometimes in its favor as it will be there when needed.

SURFACE WATER

Rain. Rain will usually stop excavating and hauling operations. In addition, it may soften stockpiles and turn pit floors and haul roads into swamps or ponds so that work may not be resumed for days or weeks.

Some pits are in such porous soil that any volume of water will soak away quickly, and neither mud nor standing water will delay work more than a few hours. Others are in such dry climates that it is better to run a small risk of water delay than to spend the necessary thought, time, and money on arranging for drainage. The majority, however, are so situated that at least routine precautions should be taken to keep them usable.

A first principle is to shape pit floors so that they will drain. In cutting into a hill, the floor should slope slightly upward toward the face so that water will flow away from this line of greatest activity. If this rear drainage is not practical, the slope may be made to the side or to channels or drains in the floor.

If the pit is sunken, drainage can sometimes be arranged into a deeper portion which will take it off the working floor and allow it to soak away gradually. This will often be a pond dug under the water table to supply the plant with water.

If pumping is necessary, it should be done from a sump that will hold a large volume of water, and in which the pump

can be protected against being covered if heavy rain falls while the pit is shut down. Such a sump may serve as a storage reservoir for plant supply.

Runoff. A pit may be troubled by water running off surrounding areas, either during rains or in the form of permanent streams, which should be diverted around the working areas, or channeled through them in such a way that it will cause minimum interference.

The best practice is to dig diversion ditches to lead the flow in other directions. However, if the pit is expanding, these ditches will require relocating and may cost more than they are worth. This is particularly likely if the ground is steep or rocky so that ditching is difficult.

Also, the water may be needed in the pit for plant or dredge supply.

If the water flows only occasionally, it can be led through the pit in wide shallow channels which can be crossed by machinery and trucks at any point. If it flows often or continuously, it should be in a ditch and taken through haul roads in pipes or on rock paved fords.

GROUND WATER

Layout, machinery, and methods in a pit may be affected by the water table, or level of ground water.

This unseen water surface may be practically level, evenly sloped, or irregular. The water generally appears to be stagnant, but it is almost always in slow motion and will slope down from the source to the outlet. The angle of this slope is the hydraulic gradient which is determined by the resistance of the material to the passage of water, the pressure and volume of the supply, and the relative heights of inlet and outlet.

Porous materials, such as gravel and sand, have low gradients, and tight ones, such as silt or clay, steep ones.

The water table tends to follow the slope of the land, but at reduced grades so that it will be further from the surface in hilltops than in valleys.

Above the true water table is the so-called capillary table which is kept wet by water rising in the spaces between soil particles. The finer spaces cause greater rise in heavy soils than in porous ones. Capillary water gives comparatively little trouble in clean sand and gravel, but causes serious softening of other soils.

Capillary water may come up higher when ground is compressed, as under a haul road.

Underground water ranges in quality from fine spring water to solutions of salt or chemicals unfit for any use.

A shallow pit may be kept well above the water table, which is then of little interest except as a source of water for processing. A pit carried sideward into a hill may cut into the table and have drainage problems of varying severity. A vertical cut will get in water eventually, except in arid climates, or exceptionally tight formations.

Surface water falling into a depressed pit as rain, or flowing into it from adjoining areas, must also be taken into account in coping with the ground water.

Permanent plants and all year haul roads should be above the highest water levels.

When it is necessary to use materials lying at or under the water table, they may be obtained by wet digging, digging in dry seasons only, draining, pumping, and by combinations of these methods.

Digging Under Water. Any machine which can dig from the top of a bank can dig under water to some extent. However, there are a number of special difficulties, including inability to see the work, weaker penetration because of decreased bucket weight and interference of water currents, loss of material carried out of the bucket by water, and sloppy condition of the spoil. Wet banks are also more liable to cave under a shovel.

Loose underwater material, such as sand,

is most efficiently dug with a clamshell, as it is securely held in the bowl while being lifted. In more cohesive bottoms the dragline is preferred because of its greater production.

Hoes suffer maximum loss of load from water currents and often show poor penetration as well. Their reach is not adequate for most wet digging and they cannot dump sloppy spoil far enough away to keep from getting in it.

Cable excavators, in proper material, can dig large pits to a great depth from a single mast position. The drag scraper will bring in better loads of fine loose material, and the slackline will dig deeper and is faster, particularly on long carries.

If a lake or river borders a pit, or a large enough pond is dug in it, a hydraulic dredge can be trucked in, assembled, and floated. The largest dredges may be able to cut a hundred feet under water, but forty feet is the maximum depth usually recommended. The spoil is usually pumped through a pipe line directly into a processing plant, but storage piles can be built. It is also possible to put the plant on the same hull as the dredge and discharge processed material into barges or conveyors.

The dredge can also enlarge the pond by undermining banks so that they cave within reach of its suction. High banks that do not slide should be lowered by land machinery to avoid danger of damaging the dredge when they come down.

Unless the pond is very large, or has a large inflow of water, the dredge may depend on a prompt return of water pumped out with the spoil. If the product does not contain many fines, water may be returned direct to the pond through a pipe or sluice. Fines can be filtered by allowing it to drain back through gravel or sand, or by holding it a while in a settling basin. In either case a larger water supply may be required than for direct return.

When the dredge has cut the working area to the maximum depth allowed by its ladder, it may be possible to reach further supplies by lowering the pond level. This may be done by partial drainage, by diverting the waste water from the plant into other drainageways, or by combining diversion with pumping.

If the material is soft enough not to require cutting, suction pipes can be extended below the ladder to the desired depth, but recovery will probably not be complete.

Care should be taken not to locate sunken and wet pits where they will interfere with the orderly development of higher layers. It should be remembered that drainage through a bank may cause it to settle to a very gradual slope, which might run it much further back into the pit floor than was intended. This type of spreading is particularly apt to occur when the pond is used as a water source, and waste water returned by being allowed to soak into the ground.

Drainage. The costs of wet digging are generally higher than doing the same work dry. If the ground surface slopes down far enough in the vicinity of the pit, it may be more economical to undertake even a large drainage project than to dig wet or to pump.

Draining is particularly feasible when spoil from an open cut ditch is of the same type as that which is being mined in the pit.

Where possible, provision in the original work should be made to drain to the full depth of the outlet or of the deposit. This may involve a very wide top cut, stable side slopes, and trucking out of spoil. If the spoil cannot be used, trenching, installing of drain pipe, and backfilling may be more economical.

Sometimes it is practical to run a tunnel, or one or more drilled holes, from the low spot into the edge of the pit area where a connecting surface shaft can be sunk. Each level can then be connected in turn to drain into the shaft. Precautions must be taken

against the entry of dirt or trash that might block the tunnels.

Sand and gravel will generally drain into either a shaft or trench with little further attention but other deposits may require trenching of various types. The problems are similar to those involved in digging and draining a large cellar, and are discussed in Chapters 4 and 5.

When a side hill cut gets into water, a curtain drain may be required at the toe of the bank to avoid damage to the floor from seepage or flowing water.

A high water table may be supported by an impervious layer separating it from well drained formations, as in Figure 10-28. Such a perched water table can be drained by drilling or digging into the porous layer below.

Surface ponds on sand or gravel deposits will often drain if the silt layer on the bottom is opened. A few sticks of dynamite exploded on the pond floor, or a shallow dragline cut, may do the work.

Pumping. When drainage is not practical, water may be removed by pumping. This may be the preferred method if the water can be used in the processing plant, then discharged outside the pit.

Pit pumping follows the practices described in Chapters 5 and 6. It usually consists of removing open water standing against or over the deposit being dug. A small sump is generally made by digging part of the hole deeper and the suction hose placed in that.

Success in pumping depends on the relation between the volume of water in the hole and the rate of inflow, and the capacity of the pump or pumps. Costs per gallon are usually smaller, and work can be started or resumed more promptly if the pumps are oversize and can handle many times the volume of inflow, so that a large part of their capacity can be used to lower the open water.

Extensive gravel layers may contain billions of gallons of water over areas of many square miles which will drain into the sump. If no rain falls, the rate of flow gradually declines as the continued drainage flattens the hydraulic gradient, but this situation requires handling so much water that expenses are usually too high.

If the gravel is of limited depth, much of the inflow might be sealed by cement grout forced down into the gravel at pit boundaries, or where flow channels are suspected. Pumping should be stopped before and during the grouting.

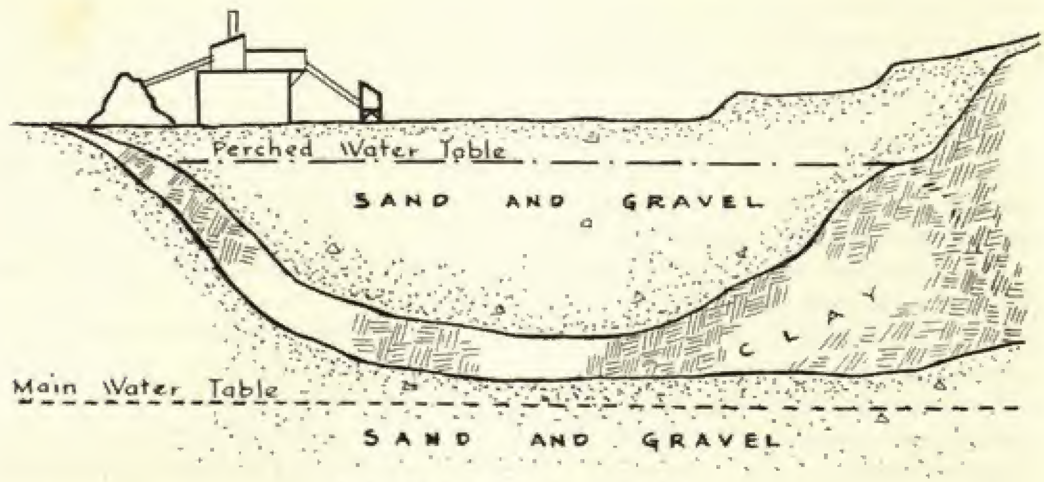


Fig. 10-28. Perched water table

In gravel formations of limited size, and in tight materials such as clay and peat, the original rate of inflow usually declines rapidly, and the underground reservoir may be exhausted so that inflow will stop until it rains.

Each time a wet pit is enlarged by working, the pumping job of re-opening it becomes greater because of the increased pond volume.

Pumping should be done in dry seasons when the water is lowest and interruption from rain least likely. In general, it is better practice to pump out, dig a large volume as quickly as possible, and allow to refill than to maintain pumping and a slow digging rate over a long period. This is particularly true in the porous, quick filling formations.

Both surface and underground water are sometimes removed by pumping out of deep wells drilled in the pit floor or near its boundaries. This method is particularly suited to plant supply.

PIT PLANNING

Pits may be opened casually by digging in a roadside bank, or large sums may be spent on investigations, plans, road building, and site preparation, before work is started. Most of them start with small equipment and output and increase in scale if they prosper.

If a contractor can dig in his own land, or on a fixed price per yard basis elsewhere, and no access road is required, no investigation of the deposit may be necessary.

On the other hand, if a large scale operation is planned involving plant and other equipment bought specially, the building of haul roads, clearing and stripping, or if the deposit is of such value that every yard must be removed, the formation should be carefully investigated for extent, quality, accessibility, and water conditions. An option to buy or to develop should be secured before this investigation.

Zoning. In many areas, zoning regulations absolutely prohibit opening a pit as such. Frequently, however, if it can be shown that the land will be improved by the work, other types of permits can be obtained which will allow limited or complete operations.

Favorable conditions include deep road cuts through hills and the removal of underwater deposits to make a lake. Other projects include taking away ridges that block view or drainage, or leveling of land for residential or industrial development.

Sometimes a community will rezone an area for the purpose of preventing the opening or expanding of a pit. If the developer has purchased the land for the specific purpose of mining it, he has a fair case against the legality of such a move. If he has already started work, such zoning would probably not be enforceable against the area being dug, but would limit expansion.

It is probable that restriction of mining has been carried too far in many areas. Where acute shortages of sand and gravel exist, there are sometimes millions of yards of these materials made permanently inaccessible by reserving the land for houses which could just as well be built on the pit floor after digging.

On the other hand, there is no question but what a pit in a residential community is a dust, noise, and traffic nuisance, and is all too often an eyesore as well. A pit operator who takes care that no machinery is operated without mufflers, or on Sunday; that calcium chloride or oil is used freely to keep down dust; that the floors and banks are kept trimmed and reasonably neat, and that finished areas are promptly topsoiled and planted, will encounter minimum resistance to expansion or to opening other pits in the vicinity.

Wherever possible, operations should be screened from the public view by leaving or planting trees and shrubs, or by natural or artificial ridges covered with vegetation.

Permits. In areas which are not zoned against digging, it still may be necessary to get both state and local permits to operate, and to put up bonds to guarantee that the area will be smoothed and planted afterward.

Heavy fines may be imposed for any failure to abide by such regulations.

Investigation. The only certain way of finding exactly what is underground is to dig it out. However, test boring or digging, mapping of surface indications, study of other pits in the same formation, consultation with geologists, and talks with local old timers may give an adequate picture of conditions.

Test boring includes making shallow holes with a hand auger, and sinking deep holes with auger, well drill, or core drill equipment. Augers generally give an accurate picture of formations they can penetrate, except that they may mix spoil from adjoining layers to a confusing extent.

Well drills pound everything they meet to sand or chips, and because of the churning action of the water, will erode loose formations around the hole, and mix their debris with that produced by the bit. Considerable skill is required to interpret these wash borings and results are sometimes uncertain.

Wash borings may also be made by diamond drills, using a solid instead of a coring bit. The hole is usually smaller and can be sunk faster, but the same criticisms apply.

Core drills will not always pick up loose material satisfactorily, but will produce excellent and reliable samples of rock.

If the soil does not cave, quite deep shafts can be dug by a clamshell of sufficient bucket weight. Information should be obtained from the spoil, or the use of mirrors in the shaft, as the possibility of collapse makes it unsafe to go down to take a look unless heavy shoring is installed.

Any hole or shaft should eventually indicate the water level. In porous soils this takes a few minutes, in tight ones as much as a month. If a record of the seasonal rise and fall of the water is to be kept, the hole should be lined with perforated casing, unless it is in rock.

Market Analysis. The next step is to figure the extent and durability of the market for the products to be mined, and the likelihood of competition from similar projects, or from small workings with less overhead.

If the total consumption of the products within shipping range is small, investment in a big plant would be inadvisable unless new outlets could be opened by lower prices, superior quality, or building of consumer plants. If the demand is large, but is already adequately supplied, the question will be whether the new pit can supply better material or service, or cut prices, or create additional demand. The efficiency of existing pits and the extent of their reserves should be studied.

If the potential market is large, and the supply limited, the question of future competition will depend on the availability of similar material to others, and whether the intended plant will retain its relative efficiency long enough to repay its cost.

The amount of processing required to fit sand or gravel to specifications of highway departments and other wholesale users may be an important factor in costs.

Capital. A contractor already operating in other lines may not need to make any extra investment in a pit until business is brisk enough to justify it. In general, however, the minimum capital required consists of down payments on machinery and land or digging rights, and money to carry payroll, operating expenses, and installments until there is income to take care of them.

If the pit must build up its market gradually, or if the demand is seasonal so that stock piles are accumulated throughout the year, to be sold during a short period, sub-

stantial capital will be needed to carry through the slack periods.

The necessity of selling on credit so that short to long periods elapse between loading the material and getting the money, will sometimes tie up more capital than all the other investments combined. This problem is discussed in the next chapter.

The risks of pit operation, as of any business venture, are greatly increased by a lack of surplus funds or borrowing capacity reserved for emergencies.

Selling Without Loading. A pit may be opened or operated without capital by the owner of the land or digging rights, by selling material "in the bank" to customers who will dig it themselves. Such arrangements are usually based on a price per yard, measured either in the bank or in the trucks. Occasionally, a certain portion of the deposit is marked off and sold, or the buyer may be allowed to dig all he needs for a certain job, for a lump sum.

A customer taking a substantial amount is usually expected to do his own stripping of overburden, keeping his section of the pit orderly and doing any required pushing back of topsoil after completion.

Sales of bank yards involve measuring the ground surface before and after their removal. This is usually done by surveyors, who work out a grid or a series of profiles. The original measurement may be fairly expensive. Later ones are much cheaper if the bench and location marks have not been disturbed. This method is best adapted to large yardages.

Occasionally, such measurements are made at the fill site rather than the pit.

Sale by truck yards usually involves measuring the trucks and counting the loads. Unless the rate of excavation is very rapid, it is apt to be impractical to assign a man as a counter. It is common practice to measure the trucks first, agree as to how much of a heap is to be carried and how much of it paid for, and then depend on the buyer's records, or end of day checks with the shovel and truck operators. The seller is then exposed to being gypped, but he may lose less than he would spend measuring the bank or hiring a checker.

A bank yard has more material in it than a loose yard because of swell. A price of forty cents in the ground may be equivalent to fifty cents in an accurately measured and charged truck. If the same price can be obtained either way, the extra yield from the bank measurement should soon repay the cost of a survey.

There is sometimes a question as to the accuracy of measurement, but on the whole, sales by bank yards or pit section require minimum bookkeeping and fuss, and are productive of fewer misunderstandings than either loose yards or material-for-job arrangements.

It is often necessary to limit a buyer to a small area so that he will not wander around picking out pockets of especially good material, making unsightly holes, and leaving sub-standard remainders.

Working Space. A pit which sells direct from bank to customer may require only enough working space to back in a truck. However, it is usually desirable to have a flat area in which to park idle machinery, to pile topsoil or other good material not immediately salable, and to place boulders and stumps until they can be disposed of.

If a crushing, screening, or other processing plant is used, space requirements are greatly increased. It is unusual to be able to sell products in the same proportions in which they are produced. There is usually a surplus of one or more grades that must be stored for future sale.

Since it is often easier to ship direct from the plants than to reclaim from storage, piles may grow when demand for their particular item is weak, and remain untouched when demand is good. This may result in steadily increasing storage requirements as the pit is enlarged.

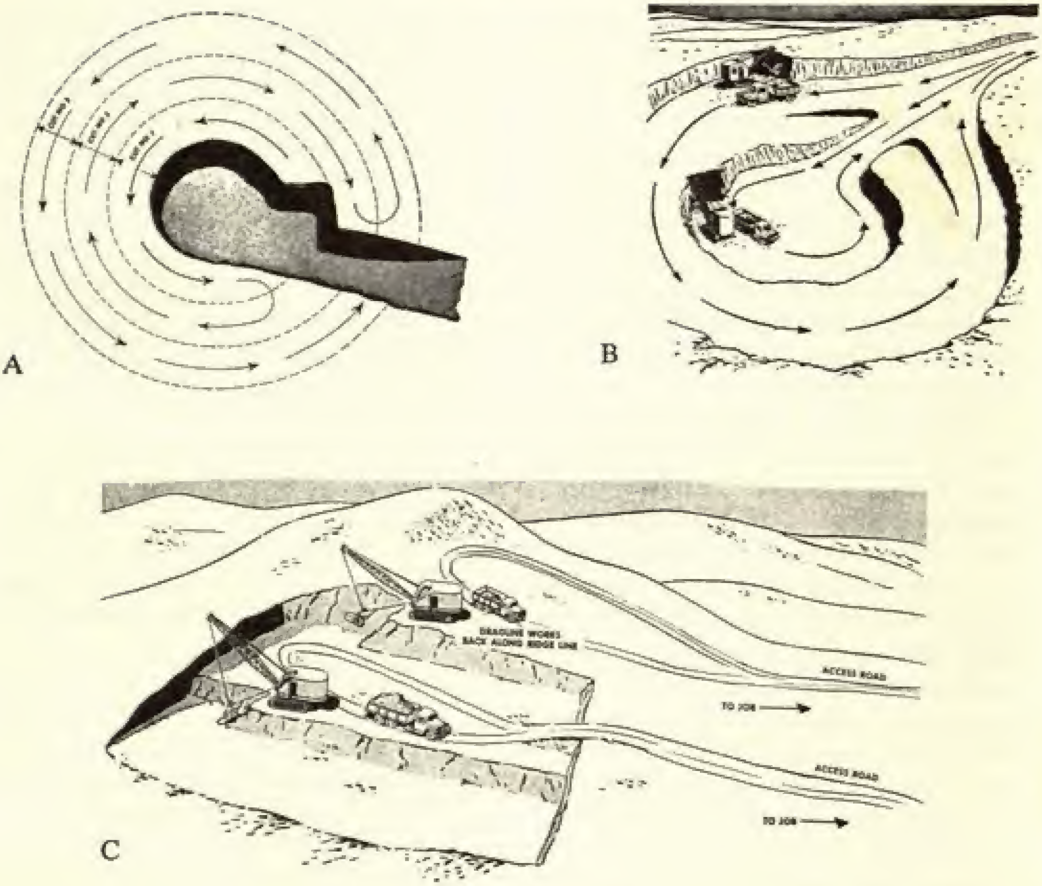


Fig. 10-29. Pit patterns

If a pit is started in a small way and preserves a more or less level floor while being dug into a hillside, storage area may increase automatically with requirements. But if a big operation is to be started full scale, level land outside the pit area must be obtained or built up with waste overburden.

If the pit is to be sunk vertically, its area is not suitable for either plant or storage. The theoretical turnover of stock piles may be such that the material would be reclaimed before it would have to be removed ahead of the digging, but this is liable not to work out in practice.

The plant is almost always located at or near the original ground level, and hauling products down to any of the cut benches for storage, and back out to sell, would be uneconomical. This type of pit will require storage space outside of the digging area which is best provided at the beginning of the work.

Excavating Patterns. Hill pits may be opened by a straight cut in or by benching. After reduction to the level of the surrounding land they are dug as sunken pits.

Subsurface workings, called sunken or dig-down pits, may be opened with shovels and ramps, or by dragline or hoe work from the top, in much the manner of a haul away cellar excavation. The circular pattern shown in Figure 10-29 (A), and (B), is also widely used, both for subsurface and slopes with gentle gradients.

Draglines can take gentle slopes in a

series of benches, as in (C). It is necessary to level a strip for walking as accurate loading with a dragline is difficult if it is on a slant.

Plant Location. A permanent or semi-permanent plant should be as close to the digging as it can without being in danger from blasting and slides. If the pit is wide, or includes many sections, the plant should be near the center, or the side which produces the greatest yardage.

Dig-down pits may supply the plant by means of ramps and trucks, trucks with cable assists, vertical bucket conveyors, clamshells, or elevators. If supply is vertical, the plant should be located on the pit edge, or as near to it as firm footing can be found. This method is ordinarily used only in rock pits, but not all rock will support a factory on the edge of a cliff.

If the spoil is trucked up, it is best to locate the plant well back from the pit to allow for ramps, storage, and room for expansion.

PROCESSING PLANTS

This heading includes screens, crushers, and washers with their feeding and discharge mechanisms. These units will be described in Chapter 21, and are discussed here only in their relations to pit layout and other operations.

Portable Plants. The simplest screening equipment is that described earlier in connection with topsoil. These pickup or skid grizzlies can be used wherever a shovel can work, but require ramps if they are to be used with tractor loaders. Their product is not well graded as narrow oversize pieces pass through readily.

Mobile plants having screening, usually crushing, and occasionally washing, equipment mounted on one or more wheeled trailers, require from a few minutes to several hours to move up to a bank and start work. Short moves in the pit require less down time than highway transportation as conveyors and other projecting parts need not be removed or folded in.

One of these units is usually able to eliminate primary hauling or to reduce it to a single truck shuttle, or a short conveyor. For direct loading from a low bank, particularly by a short-range excavator, it may be desirable to keep a tractor constantly on hand to move it up.

The use of portable units allows almost as much flexibility as in direct-from-the-bank selling. However, highway requirements keep their maximum size and weight below that required for many jobs; and the necessity of packing everything neatly in minimium space causes them to be harder to service than fixed plants of the same capacity.

They can often be used profitably for handling the more distant banks, or for filling special orders, in a pit that has a fixed plant. They may also be used for outside jobs or subsidiary pits. Hauling is a major cost factor in gravel and crushed rock, and the ability to open and process banks near the job may be valuable.

A mobile screener and crusher will reduce the risk involved in opening a new pit. Although not very readily disposed of, they are more or less standardized, and if found to be of the wrong size and type, can be sold or turned in, with a far smaller loss than a fixed plant.

Also, the use of one or more of these units may permit the pit to be developed until adequate space is dug for a fixed plant. If the pit is in a hillside, with steadily increasing bank height, getting the permanent plant well back in it will result in cheaper primary hauling over the whole job.

Fixed Plants. A fixed plant should be the right type for the material to be processed; it must be large enough for the job and within the capital budget. The first consideration is generally the most important, for if business is good, the plant can be

expanded although at relatively higher cost; and exceeding a budget may be less damaging than getting the wrong equipment.

Plant manufacturers are ready to supply good engineering advice on every aspect of plant layout. It is a sound plan to get at least general recommendations from two or more companies, and to compare their findings with local practice. Even with these precautions, no person without a good working knowledge of the business should make a heavy investment in machinery from catalogs.

Wherever a fixed plant is placed, the cost of hauling to it will increase as the digging progresses, whether laterally, downward, or both.

Taking down, moving, and setting up a permanent plant is usually a tedious and expensive job, particularly if it is a large size. Even if it is of prefabricated, knockdown construction; rust, wear, and patching may make it hard to handle and foundations are generally left behind. Many millwrights consider it best to salvage only the operating units, and to order or build new frames to carry them.

It is usually sound policy to charge the entire cost of such a plant against the material that can be handled at its original location. If the pit area is definitely limited by property boundaries, zoning restrictions, or change of ground, and the depth of the deposit is known, the yardage can be calculated. It is best to make a liberal allowance for occurrence of unexpected masses of unusable material.

HAULING

Pit hauling includes the movement of material from the bank to the plant or to storage, and between the plant and storage in both directions. It also involves delivery from these three locations to the job, although a variable amount of the product may be hauled from the pit in the customers' trucks.

The principal hauling units for pit use are trucks, including semi and full trailers, and conveyor belts. Railroad freight trains, of either narrow or full gauge, are used in big pits, the latter particularly in taking raw material from banks to a distant market. Digging units such as scrapers and cable excavators may also do a substantial amount of hauling.

Conveyor belts and cable excavators and, to a smaller extent, scrapers, are largely confined to work inside pits. Trucks are equally adapted to inside hauling and outside delivery. On very long hauls, heavy materials are more economically moved by standard gauge rail.

Conveyor belts may be considered either hauling units or part of the plant itself. They move and elevate material with minimum effort, but are usually difficult to set up and to relocate. They may be used instead of haul roads and trucks for delivery of a heavy volume of material to a single point many miles away.

Trucks are excellent flexible, general purpose units. They are available in a wide range of standard sizes and can be adapted to different size loaders or production schedules by varying the number on the run.

Cable excavators require a large yardage within reach to justify setting up. They can also be used in storage yards to pile, reclaim, and feed.

Scrapers, to operate as such, need ground they can dig and hoppers which they can drive across, or storage areas giving them room to maneuver. Banks which they cannot dig can be loaded into them. However, scrapers are more costly and are usually slower than dump trucks of the same size, so it is not good practice to use them steadily under shovels.

A scraper can dump beside a sunken hopper which is kept filled by a dozer.

Truck hauls may be kept short by adding conveyor belts to the plant. The new belt

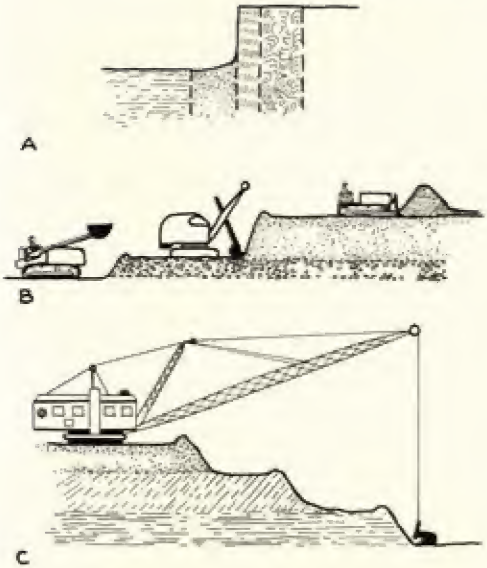


Fig. 10-30. Selective digging

will dump on the receiving end of the previous belt. Such installations may be quite long and are justified whenever considerable yardage will be handled.

Hoppers which are built so that the truck can drive straight across, instead of backing to dump, are more expensive to construct but will allow a faster truck cycle. Such hoppers can also be used for scrapers.

SELECTIVE DIGGING

Selective digging may be done to separate, at the face, two or more materials of value and to remove them; to remove one or more formations, leaving unwanted material; or to dig two or more materials so as to combine them.

Any or all of the spoil from these operations may be hauled away or sidecast.

Layers. If the different formations are in vertical sheets, as in Figure 10-30 (A), any machine which is accurate enough to work the narrowest vein can be used. If they lie horizontally, as in (B), any excavator can move them if they can be cut as separate banks. If they are horizontal, and two or more must be removed at once, the excavator should be able to work from the top down. If divisions run in several directions, and separation must be exact, a clamshell, with assistance from hand labor, is probably required.

When horizontal layers are separated by a dragline, as in (C), it should have a boom at least twice as long as the bank is high. The boom angle should be low and the dump cable short to make possible picking up the bucket at a distance.

A clamshell can do the same work with a shorter boom as no allowance need be made for space to drag the load.

Inclined strata fall into any of the above classes. In general, it is bad practice to remove enough of any layer to leave the one above it overhanging.

Selective digging is quite commonly required in stripping overburden, and in gravel and clay pits. The operator may have the responsibility of choosing the section of bank most suitable to plant or customer requirements, and supplying deficiencies by mixing different sections or layers.

Mixing. A good way to mix at the bank is to build a stockpile by dumping the several materials on one spot. A conical pile will be built, with each bucket load separating and sliding down the sides. A succession of very thin layers will be made which, upon redigging to load, should mix together quite smoothly.

Such a pile will tend to concentrate round or coarse pieces at the bottom, but these will be remixed in handling by a machine working from the bottom.

Mixing is also done directly at the bank by digging from one formation, dumping on another, then loading the two together.

If the layers are horizontal, digging in slices from the bottom up will mix them.

Scrapers may bring to the top of the bank material to be mixed into it by loading.

Pockets. When an irregular deposit, with

sloped or vertical edges and numerous interruptions, is dug from the bottom, a cluttered pit is left. All parts of it are accessible to digging equipment and trucks, but there may be little room to maneuver and none for storage. If the digging is done from the top, the area may become a badlands, with little or no access and probably deficient drainage.

Such areas should be dug out, or smoothed down, at the first opportunity, particularly if any further work is to be done behind or under them. Many pits have strangled themselves out of business while they had ample reserves because leaving obstacles to orderly digging has forced haphazard development with increasing excavation and hauling costs.

Cutting a pit floor by pursuing a good vein across it is a bad practice which it is sometimes difficult to avoid. In general, it should not be done unless its value is sufficient to cover the cost of backfilling. If floor and walls of the cut are smoothed off, it may be filled with material to be stored which can be recovered when the whole floor is lowered. If no further digging is to be done in the floor, the slot can be filled with waste of a type which will not become too soft to carry pit traffic.

Cuts down from a floor, whether pockets or the start of new levels, should be near the outer edges of the pit.

Boulders. A common problem in pits which are dug without blasting is the occurrence of boulders too large for the loading or processing machinery. These are found in glacial and stream deposits, in disintegrated rock, and near steep slopes.

In pits selling only direct from the bank, there is no convenient way of utilizing boulders or of disposing of them. Blasting will reduce them to a size which can be loaded, but the market for coarse rock is so limited that they may have to be sold as second grade fill, or wasted. The pit operator will generally prefer to allow them to accumulate along the bank, or will have holes dug to bury them. Occasionally, an abandoned pit is close and deep enough to permit disposal by pushing them over the edge.

If allowed to remain where they fell out of the bank, or pushed into occasional piles, they will present obstacles to orderly development similar to those left by pocket digging. In general, the nuisance value increases with the size of the pieces, relative to the power of the dozer which must handle them.

It is occasionally possible to sell boulders for use in jetties or breakwaters, at a price high enough to justify hiring a machine big enough to load them.

STOCKPILING

Stockpiling is most efficiently done on hard, flat, clear areas. Dumping may be done on the flat, off piles, or from side banks. The location should be convenient to the face, the plant, and the market, the relative importance varying with the use of the material.

Trucks. If available space is very large compared with the bulk to be stored, trucks may dump piles against each other, as closely as possible, without further grading or heaping. Large trucks make high piles and place maximum yardage in an area.

This method takes a lot of space, forms a bank too low for efficient loading by many machines, and causes maximum danger of mixing the stored material with the floor.

If packing by trucks will not cause damage, such a piled area may be smoothed off by a dozer, and one or more additional layers added. Factors limiting the maximum height are the slope in from the edges and the more gradual grade for the truck ramp, which steadily cut in on the area available at the bottom.

Figure 10-31 illustrates the building of a stockpile by backing trucks up on the

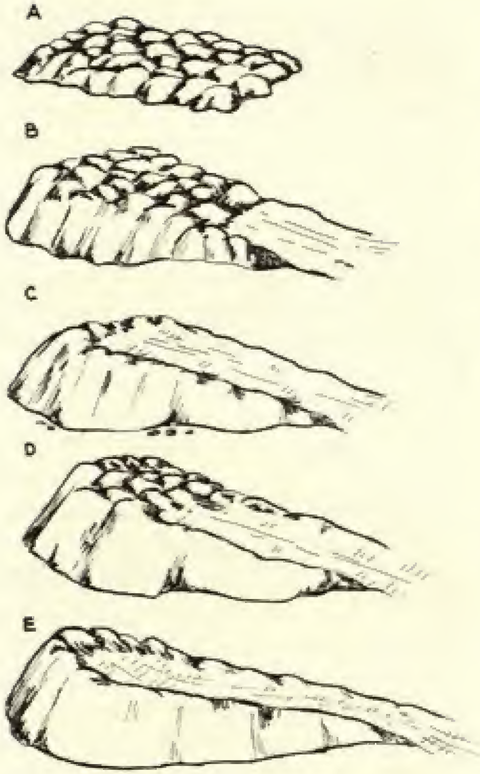


Fig. 10-31. Truck-and-dozer stockpile

dump and building it up in layers. Ramp grade should not be so steep as to strain the trucks or to prevent them from dumping cleanly.

At any time, the building of the top can be discontinued, and loads dumped off the end. The trucks are then usually driven up forward and turned on the pile.

These two methods can be alternated so that both height and area can be increased to the limits of the space available.

Figure 10-32 illustrates the building of a pile by the use of a spiral ramp. This is started as a narrow, back-up pile which is spread on the outside far enough to protect the road from caving, and well past the center on the inside. The road, steadily rising, is turned and comes back on the far side, parallel with the first section, but above it. Material is still dumped far enough to the outside to protect the road, and on the inside until its toe approaches the first part of the road. The road is then brought around again, as many times as pile area will permit. The storage area decreases rapidly with height.

Digging from any part of this pile will undermine the road and make the top inaccessible until it is rebuilt.

The pile may be extended by dumping off the road.

If the material is somewhat too soft or loose to support trucks, the road may be strengthened by the use of wire mats, or

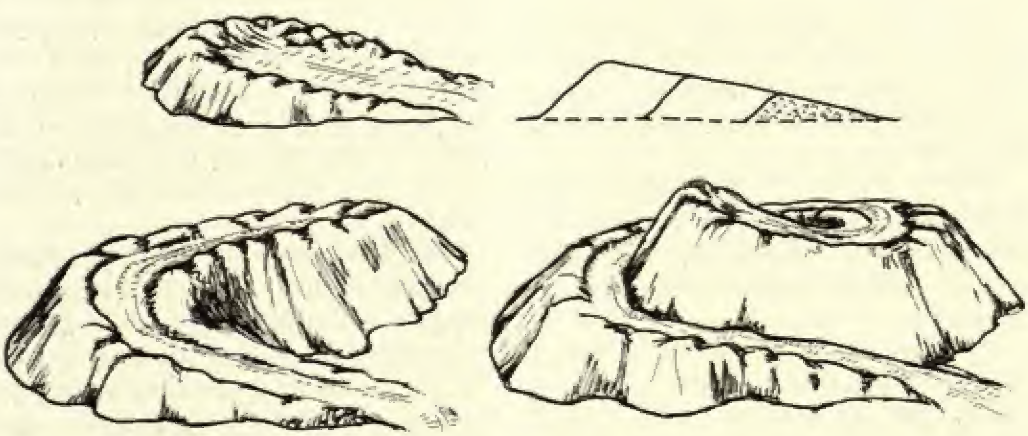


Fig. 10-32. Spiral stockpile

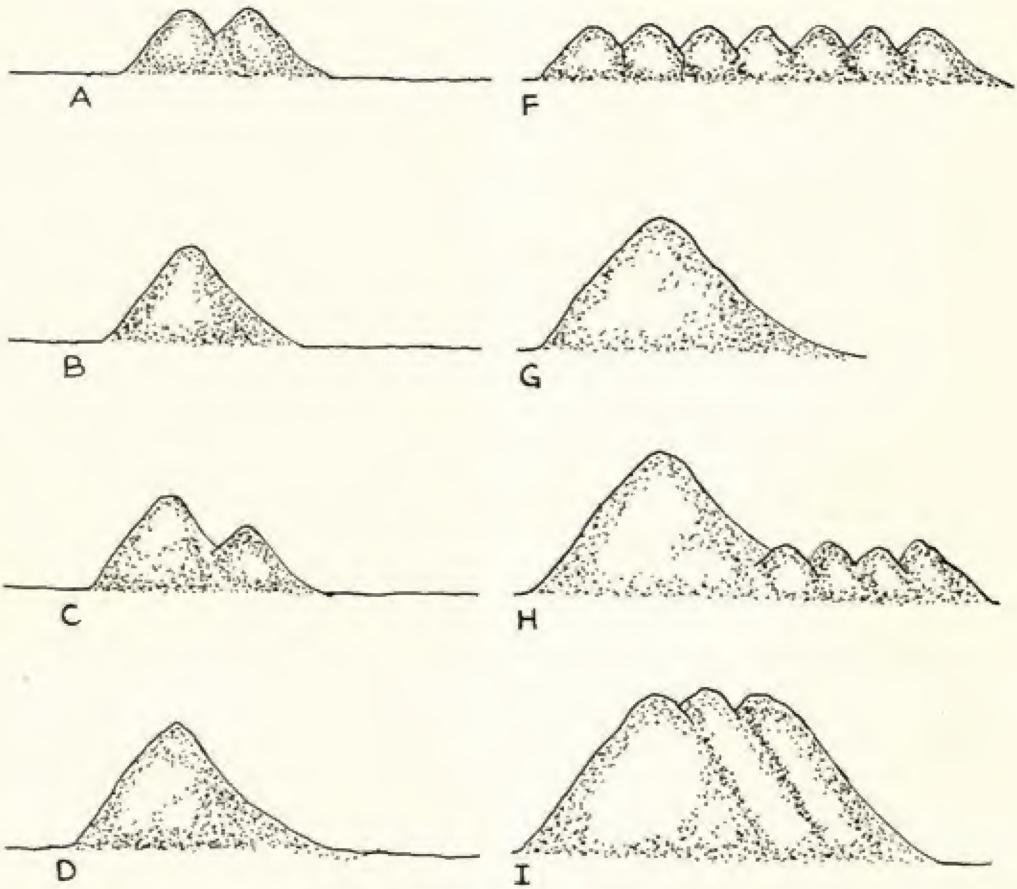


Fig. 10-33. Dozer stockpile

small quantities of screenings or other binders, if their use will not spoil the value of the stockpile.

Very loose material such as sand or round gravel should be stacked by a drag scraper, bulldozer, or clamshell.

Stockpiles may also be built by dumping off a bank.

Dozers. Dozers are necessary to the truck piling methods described. They can also be used to make heaps of dumped material without having trucks climb up on them.

If enough trucks are running to keep it busy, the dozer may push each pile up as it is dumped, as in Figure 10-33, (A) to (E). The volume the dozer can handle decreases as the height of the pile increases.

If the trucking is slow or irregular, dumping may be done closely over an area, and dozer heaping done now and then, as in (F) to (I). If the stockpile can be made into a windrow, and the dumping kept close to it, the operation is almost as efficient as immediate heaping, allows the use of the dozer on other jobs, and makes hauling and piling work largely independent of each other.

The dozer heaps up stockpiles rapidly, is entirely flexible in placing them, or varying their size or shape, and can be used for a variety of other work. However, it must move its entire weight up the pile with each load, has constantly working tracks which may be subject to severe wear in sand or other abrasive piles, and may pack or crush

soft materials so as to reduce their value.

The four wheel drive, rubber tired dozer does not exert as much push, particularly if the footing is loose, but does minimum crushing damage. Tire wear is slow in sand but may be rapid in crushed rock. Packing is more severe.

Shovel dozers can heap piles, and can also separate, carry, and load. Wheel types are frequently used to reclaim to hoppers.

Clamshell. The clamshell is commonly used for building stock piles from shallow dumps, barges, and cars. A light rehandling bucket, with toothless lips, is used for loose material on a floor.

It can be used at the same time for loading trucks from either the dump or the stockpile. It often alternates hopper loading from the stockpile with the heaping work.

It is flexible in regard to placement and shape of piles, although not as much so as the dozer. It does not crush or pack.

Drag Scraper. If the storage location is fairly permanent, it may be more economical to heap up the truck dump with a drag scraper than with the trucks and bulldozer. The mast should be high enough to allow for piling the maximum amount to be stored, and the tail tower should be readily moved so that a wide area can be utilized.

The drag scraper may also be fixed to reclaim the material with a reversed bucket, and dump it into a hopper from which it is conveyed into the plant, dump bins, or directly into trucks.

If several classes of material are to be handled, both head and tail towers may be mobile.

A scraper installation does not have the flexibility of dozers and is not available for other work. However, it is very efficient in that only the weight of the bucket needs to be pulled up with the load, it does not pack or crush the pile, and only the bucket is subject to abrasive wear.

Carrying Scraper. The rear dump scraper builds a pile in about the same manner as a truck. It can operate on a steeper ramp and in much tighter places, particularly if towed by a crawler.

The bottom dump scraper is most efficient at building a long pile, in the same manner as a highway fill. The sides are built up, starting at the outer edges, as steeply as the material will permit. The entrance ramp at one end, and the exit at the other, are started at gentle slopes and steepened as necessary. The pile may be started full length, or made short, and extended when additional capacity, or an easier ramp grade, is needed.

A dozer or a motor grader should be available for at least occasional trimming of the surface. If the material tends to get soggy when water soaked, or is unstable at the edges, compaction with sheepsfoot or rubber tired rollers might be advisable. Ordinarily, however, the scrapers themselves provide sufficient compaction for stockpiling purposes.

Scrapers may also make shallow piles for rehandling by drag scrapers.

Conveyors. Stackers and other conveyors of the boom type will build high piles with material dumped into a hopper. If these machines are wheel or track mounted, they can be towed away from the pile so that it will build into a windrow. Width of pile can be increased or separate piles made by pivoting the boom or the whole machine.

These are most easily fed by a drag scraper or revolving shovel, but a skid mounted ramp that will allow trucks to dump into the hopper can be made out of heavy timber.

Long conveyors, of either elevating or horizontal types, may be made so that a dumping device can be inserted at any spot desired. This makes possible the building of a windrow the full length of the conveyor, or making a series of separate piles of different grades. Lengthening the dump conveyor will increase the area which can be used.

CHAPTER ELEVEN

MAKING AND LOSING MONEY

COSTS

Contractors' costs may be difficult to classify, but a rough division into capital investment, fixed or overhead costs, and operating expense is convenient.

Capital Investment. This heading includes investment by the owner or owners of their cash or borrowings, in working capital, machinery, office and field buildings, processing plants, land, stocks of material, mining rights, rights of way, and similar items.

Overhead. Overhead is made up of costs which do not vary immediately or directly with volume or type of work.

It may include the following items:

Drawing accounts, or living expenses, of owner or partners.

Management and supervision—salaries of executives, superintendents, and foremen.

Office rent, payroll, and supplies.

Interest paid on loans, or charged against capital investment.

Insurance for fire, theft, and liability if paid on the ownership of equipment and premises.

Ownership taxes on land, equipment, and other capital assets.

Depreciation.

Personal Expenses. The contractor who runs his own business should keep books sufficiently to distinguish between business and personal expenses. However, he should bear in mind that these come out of the same pocket, and that his living costs are part of business overhead to the extent that it is up to the business to provide money to cover them.

It is common practice for owners to draw a fixed amount, and to consider this to be the only personal charge on the business. However, if personal expenses are in excess of the drawings, and the difference results in running up bills, these will ultimately have to be paid by the business, and might better be considered a charge against it from the first.

If personal expenses are not closely accounted for, a one-man business which is profitable in itself may go steadily downhill, without the proprietor ever understanding why.

Job Overhead. This heading may include any of the overhead items which are increased to take care of a particular job. When a contractor takes on a big project, his office and supervision force may be enlarged several hundred percent for its duration. This increase, arising from the one job, can justifiably be charged against it.

If job conditions require providing guaranteed pay, meals, rooms, or services to field employees, such expense may be labeled overhead, operating, or job overhead.

Job overhead may also include a proportion of home office overhead.

Job records show time for men and equipment, as well as cost, as reference in figuring other jobs in which the work is similar but costs are different.

Operating Costs. This heading includes:

The field payroll of employees hired by the hour or day, or for the job.
Payroll taxes.
Liability and compensation insurance based on payroll, work, volume, or job conditions.
Machinery fuel, lubrication, maintenance, and repair.
Machinery rental, delivery, and changing rigs.
Expendable supplies.

Receivables. An important consideration for a contractor or a pit operator is the amount of capital required to carry customers' accounts. In most localities it is difficult or impossible to work on a cash basis. Even when the primary business is selling a commodity in great demand, as gravel in a gravel-scarce area, and operations are started successfully on a cash-for-each-load formula, good customers have a way of working away from it through a series of steps, such as pay after several loads, pay at the end of the day, at the end of the week, and at the end of the month, to a regular charge account, perhaps tying up thousands of dollars for long periods. Losses on jobs, or difficulty in collecting accounts, may change a well-heeled customer into a slow paying one.

Credit granted to one makes it triply difficult to refuse it to others.

It takes more backbone, or perhaps uncooperativeness, than is possessed by the average contractor to resist this technique of opening and increasing accounts. Also, it frequently happens that the pit cannot maintain a profitable volume except on credit, particularly if competitors enter the field.

Receivables not only tie up a large amount of working capital, but include a probability of bad debt losses. These can be minimized by good judgment in extending credit and skillful collection methods, but they cannot be entirely avoided.

A bank is usually willing to lend money on receivables. If the account has a good credit rating or local reputation, it may advance the full amount, less a discount which serves for an interest payment, on the understanding that any money received from that customer goes directly to the bank. Or a certain portion of the total amount of receivables may be lent on a regular interest bearing note.

The cost of such discounts or interest, and an allowance for uncollectible accounts, should be figured into the prices charged for material and services.

Offering discounts direct to the customer for cash or prompt payment is helpful in bringing quick money from good accounts, but is not very effective with those who are really hard up, and who constitute the major problem.

If a pit is operated partly with owned machinery, and partly with units rented from others, an over-large or doubtful account can often be tactfully collected by hiring the customer's machinery until he has worked it off. Sometimes an arrangement is made by which the pit pays the customer partly in cash to enable him to keep up with his payroll, and applies the balance against the bill.

MACHINERY COSTS

Equipment cost should be figured in two ways—total expenditure involved in buying the machine and starting work; and cost

of ownership and operation during its useful life. These are different ways of looking at the same thing and should never be added together.

The expenditure is the important figure to the contractor with limited capital, but may be merely a factor in considering long term costs for the large operator.

Care should be taken to include in the purchase price all expenses involved. These may include list price, delivery to the freight station, and perhaps then to the job or yard; accessories, such as cabs, lights, spare tires, parts, and special tools; repairs or alterations necessary immediately; allied equipment required to get full use of the machine; and finance charges in excess of normal interest rates.

Some of these items are self-explanatory. Repairs are required only on used machines and include such items as replacement of worn tires or tracks, or complete overhaul.

Alterations may be changes made to adapt to overloads or special work, or may be necessary to correct mistakes or omissions of the manufacturer. They can include fishplating and other types of reinforcement, building up wearing surfaces with hard steel, safety guards, and other devices.

Allied equipment covers such extras as a trailer to carry the machine, ramps for loading it, and different front ends, buckets, or blades for special uses.

Finance charges may be at a higher rate than ordinary business discounts, and often include insurance and other charges. These are usually added to the face amount of the sales contract.

Ownership. This is what it costs to own the machine aside from the expenses of operating it. It may be figured on an hourly, daily, monthly, or annual basis, or over the whole expected life. Usually, it is figured on an annual or whole-life study, then divided into shorter periods.

Depreciation should be included. This is the original cost of the unit divided by the time it should work. According to the Internal Revenue Department, most construction equipment is worn out or obsolete in three to six years, and depreciation may be calculated accordingly. On the other hand, it may be that the contractor is accustomed to using the type of machine he is buying for ten to thirty years, and will wish to figure on that basis.

Some foreign governments rule that a machine depreciates each year by one third of its value at the beginning of that year.

Several methods of computing depreciation are now authorized by the U.S. Treasury department. These are discussed in the Appendix, Page A-33.

When a machine is sold for less than its depreciated value, the deficiency is a capital or a business loss. If the price obtained is higher than such value, the difference is either capital gain or income.

If the machine is turned in on another similar unit, the part of the allowance which is greater or less than its book value may be used to decrease or increase the book value of the new machine.

Interest should be charged against a machine even if it is bought for cash. Money spent on it could have been used to pay off indebtedness; or invested so as to yield a return, as in bonds or savings accounts. The interest rate is usually figured to be between four and six percent on the average annual investment.

This average investment is found by adding one year to the depreciation period, dividing by twice that period, and multiplying the resulting fraction by the original cost. For five-year use, the fraction would be $\frac{6}{10}$, for six-year, $\frac{7}{12}$.

Insurance costs will include fire, theft, and collision coverage for the machine itself, and sometimes liability insurance, either as a separate policy or as an increase in premium for general coverage.

In many states, machines are taxed as personal property in the same manner as

real estate. Trucks and rubber mounted machines that travel on highways pay license fees, which are a type of tax.

Operating. The cost of operating a particular machine is made up of operator's pay, fuel, lubrication, and repairs.

Pay should be figured to include payroll taxes, pensions, cost of or loss on board, lodging, transportation, and other extras, and liability and compensation insurance based on payroll.

Fuel consumption varies, but is usually figured on an average basis. A big machine takes more than a small one, and hard work consumes more than light jobs. Gas engines use more fuel and higher priced fuel, than diesels. Proper engine maintenance will keep fuel bills down. Careful maintenance increases lubrication costs but they are saved many times over in reduced repairs. A rule of thumb which can be used unless there is evidence to the contrary, is that lubricants, and the labor of using them, amount to 50 percent of fuel cost.

Repairs include maintenance items such as cables, hydraulic hose, filters, tires, and blade edges, field repairs, and complete overhauls. These vary greatly among different types and makes of machines, with the type of work, the treatment the machine receives, and luck. The rule of thumb is that over the life of the machine they will equal its first cost.

Hourly. It is convenient to figure machine costs, both ownership and operating, on an hourly basis. If the calculations have been done on a yearly method, the results are divided by the number of hours of work which the machine should do in the year.

A single shift, forty hour week will afford a maximum of 2,100 working hours in a year, but weather, holidays, repair time and other shutdowns will usually reduce this to 1,000 to 1,500 hours. Overtime work, or operating two or more shifts, will increase the number of working hours.

Increase in number of working hours will usually decrease ownership cost per hour. Increased working hours will affect operating cost only insofar as overtime or other factors raise the pay rate.

Sample calculations of hourly costs are shown in Figures 11-1 and 11-2.

The first is based on a 1500 hour year. The second, a standard type of approach used by most manufacturers, uses a 2000 hour year. In either case the machine might actually run many more or fewer hours than expected.

If the machine can be sold at the end of its work life, ownership costs are reduced. This factor is too variable to be counted on.

In Figure 11-2 the tires are deducted from the capital cost of the machine, and re-entered under operating costs. This makes no difference in the final combined hourly cost, but does point up the high cost of tires, and the importance of taking care of them.

Crawler tractor figures might be set up to show cost of tracks and rollers as an operating expense.

Many contractors can buy replacement tires wholesale, thus substantially reducing costs under this heading.

OVERTIME

Where the excavation industry operates on five working days of eight hours each per week, additional hours worked on any of the five days, and any time worked Saturdays, are called overtime, and paid at one and a half times the regular hourly rate. Sunday work may be time and a half, or double time.

A contractor who must finish work before a contract deadline, or before bad weather, or who wishes to take advantage of a busy season, may ask his men to work overtime; hire additional men to work two or three shifts; or may buy or rent additional equipment to work one shift.

In general, it is profitable to work large machines overtime, as the extra wages are

List price FOB factory		21,400.00	
Freight		500.00	
Extras and alterations		600.00	
	TOTAL COST		25,500.00

Estimated yearly use	1500 hours	
" life	5 years	
TOTAL USE	7500 hours	

Average annual investment	$\frac{6}{10} \times 22{,}500$	=	13,500.00
Depreciation per year	$= \frac{22{,}500}{5}$	=	4,500.00
" per hour	$= \frac{4{,}500}{1{,}500}$	=	3.00

Estimated yearly	interest	= 5% of av'g annual investment		
" "	insurance	= 2% " " "		
" "	taxes	= 2% " " "		
" "	overhead	= 9% of 13,500	=	1,215.00
" hourly	"	$= \frac{1215}{1500}$	=	.81

Depreciation per hour	3.00	
Overhead " "	.81	
Ownership cost " "		3.81

OPERATING COST

Operator's hourly wages, assumed	2.00	
Hourly taxes and insurance on wages, assumed at 15%	.30	
Fuel, diesel	.60	
Lubrication, ½ fuel cost	.30	
Maintenance and repairs, assumed equal to depreciation	3.00	
OPERATING COST per hour		6.20

TOTAL HOURLY COST, OWNERSHIP AND OPERATION	10.01

Fig. 11-1. Ownership and operating cost

ESTIMATED HOURLY OWNERSHIP AND OPERATING COSTS

18LDT-105W - 25yd. Bottom Dump

(Includes Cab)

OWNERSHIP COSTS

1. DEPRECIATION: (No allowance made for salvage or resale value.)

Purchase Price	$42,440
Extras	$
Freight - (60,800 # @ $ 1.50 /100#)	$ 912
Delivered Price	$43,352
Less Original value of tires (see No. 3 below)	$10,925
Total Amount to be Depreciated	$32,427

Divided by depreciation period - 10,000 Hours: $ 3.24

2. INTEREST, TAXES, INSURANCE and STORAGE:
(10% : Interest 6%, Taxes 2%, Ins. & Strg. 2%
Estimated at 10% of average yearly investment:
Average yearly investment for 5 years is 60 % of delivered price.

$$\frac{\text{Delivered Price } (\$43,352) \times (60\ \%)}{\text{Hours Operated per Year } (2,000)} \times 10\% = \$\ 1.31$$

A. TOTAL HOURLY OWNERSHIP COST $ 4.55

OPERATING COSTS

3. TIRE REPLACEMENT COST: (Includes Tires, Tubes & Taxes.)

Front Tire Size	14:00 x 24 -	20 ply; 2	reqd. -	$ 767
Drive Tire Size	27:00 x 33	30 ply; 2	reqd. -	$ 5,079
Trailer Tire Size	27:00 x 33	30 ply; 2	reqd. -	$ 5,079

Total Value of Original Tires - $ 10,925

Divided by Estimated Tire Life of 5,000 Hours: $ 2.19

4.	TIRE REPAIRS, estimated at 15 % of Hourly Tire Cost	$ 0.33
5.	REPAIRS, including parts and labor	$ 1.42
6.	CUTTING EDGE REPLACEMENT COST - estimated at (Scraper only)	$
7.	FUEL, est. consumption 6 gal./hr. @ 14¢ /gal.	$ 0.84
8.	OIL, GREASE - including greasing labor.	$ 0.25
9.	OPERATOR - including Social Security and Compensation	$ 1.50

B. TOTAL HOURLY OPERATING COSTS $ 6.53

TOTAL ESTIMATED HOURLY OWNERSHIP AND OPERATING COST* $ 11.08

See EUCLID'S booklet, "Estimating Production & Costs" Form 355, for additional estimating information.
*DOES NOT INCLUDE PROFIT, OVERHEAD AND SUPERVISION

APRIL 10, 1953

Courtesy of Euclid Division, General Motors Corporation

Fig. 11-2. Costs, 2000 hour annual basis

more than offset by the drop in hourly ownership costs caused by spreading them over a greater number of hours. Small machines may show either increased or reduced profits.

Overtime work with labor, supervisors, and other personnel ordinarily results in a loss, as the profit figured on a payroll is liable to be between 15 and 25 percent, as against the 50 percent increase in pay rate.

It should be remembered that payroll insurance premiums increase in direct proportion to the amount of pay, although some payroll taxes do not apply over a certain amount.

The small contractor whose machine operators are frequently able to work for extended periods without help or supervision, is more likely to work overtime than the large scale operator.

When work is being done on a fixed price contract, or at a fixed hourly rate, overtime costs must be carefully watched. If the work is on a basis of cost plus a fixed fee, overtime will merely require a larger investment to obtain the same profit. If payment is cost plus a percentage of cost, overtime, as well as any other extra expenses, will increase the contractor's profit.

Cost-plus contracts may require that a contractor obtain written permission before incurring overtime or special expenses.

Multiple Shifts. Work may also be speeded by working two or three shifts. Three shifts are commonly eight hours each, one crew taking over from another without any shutdown. The day shift is from 8:00 A.M. to 4:00 P.M., the "swing" until midnight, and the "graveyard" until the day gang takes over. Pay time is eight hours, but a "lunch" period, and time lost in the changing of the shifts, reduces work time to less than seven and a half.

Two shifts may be of either eight or ten hours each. The job is usually shut down after each shift, except for lubrication and repair crews.

Night work is less efficient than day because of the need for artificial light, and the lessened accuracy and usually lower mental and physical vigor of the men. Night grading is very destructive of stakes.

Multiple shifts may work at cross-purposes, or at least with insufficient understanding of what has been done. This difficulty is somewhat less when the new crew arrives before the other leaves. If there is no contact, the supervisors should meet in the idle period to discuss the work and coordinate their efforts.

There should be a system for rotating men among the shifts, but it should be admininstered intelligently. Night shifts are generally unpopular, but some individuals prefer them and they should be left in them. Swapping of shifts among equally qualified men should always be allowed. Rotation should be at rather long intervals to enable the men to adjust to changes in sleep and work hours. Two weeks is the shortest period which should be considered.

ESTIMATING

A contractor is usually called upon to estimate the time, material, and expense involved in a piece of work. This estimate may involve careful calculation of all factors, may be made up from records of similar work, or the memory of them; or, in bidding on a small proposition, be only an informed guess.

An estimate may be used as a basis for making a fixed price bid, or simply to give the customer an idea of cost while performing the work on an hourly or cost plus basis.

The first requirement for most estimating is practical experience with the work involved. In large organizations, this experience may be only in handling cost, production, and time figures. In small firms, the figuring is often done by the same man who does or directs the work. He should be familiar not only with excavation in gen-

eral, but with the specific type or types of work to be done.

Bulk and Hauling. The gross factors in estimating excavations are the quantity of material to be dug, its digging qualities, the distance it must be moved, haul conditions, and the manner of its use or disposal; all in relation to the equipment to be used.

Quantity, which is usually measured in bank yards, should include anything that must be dug, quarried, or moved in the course of the work. Material which is stored and reclaimed must be added in twice.

Digging qualities will include not only the hardness and coarseness of the bank, but water or sand conditions on the pit floor, danger of slides, etc. It will largely determine the type of excavators to be used, and whether blasting will be necessary or not.

The distance to be moved will decide whether it is more economical to push or to carry it, and the types of hauling unit to be used. In general, haulage is figured from the center of mass of the cut to the center of mass of the fill, but the length of the longest and shortest hauls must also be considered.

Haul calculations should include attention to the type of ground to be crossed, its probable carrying capacity and tractive resistance, grades to be climbed and the cost of making and keeping it passable.

Spoil can be dumped over a high bank more economically than it can be spread and compacted in a fill. Operations will be slowed unless there is space for equipment to maneuver and dump in, and unless the fill will support and give adequate traction to the hauling units.

Fill requirements can be greatly increased by a soft base that will compress or shift under its weight.

Measuring Volume. An experienced estimator can often judge the volume of a bank or pile quite accurately by inspection, without measurement. However, appearances are often deceptive, and most people are safer if they make at least approximate measurements as a check.

Casual estimating or measurement of bulk is reasonable practice in small jobs, and in situations where volume is not a major factor in costs.

When large volumes are involved, careful measurements should be made by engineers or their methods. These are discussed in Chapters 2 and 8.

An excavation for a cellar in flat ground is calculated by extending the wall lines to include extra digging required outside the foundation, and multiplying length, width, and depth. The line measurements may be converted into yards, or the multiplication done in feet, and the result divided by 27 to give cubic yards.

An irregular cellar is divided, on paper, into a number of rectangular blocks. The volume of each is found and the results are added to give total volume.

The dirt to be removed for bulldozer ramps may be figured separately, or allowance made by using a lower production basis for the machine.

Piles can often be conveniently measured by calculating the volume of regular masses of similar outline, and making plus or minus adjustments for differences.

A pile of clean, dry sand may have a conical shape, or be a ridge with a triangular cross section, ending in half cones. Measurments should be taken to determine base size and height.

The area of the circular base of a cone is found approximately from the circumference by the formula:

$$\text{Area} = \frac{\text{Circumference}^2}{12.6}$$

and from half the diameter by

$$\text{Area} = 3.14 \times \text{Radius}^2$$

The volume of a cone is the height times one third the base area.

The long part of the pile is figured by the formula:

$$\text{Volume} = \frac{\text{height} \times \text{width} \times \text{length}}{2}$$

A long pile will have the volume of the center section, plus the volume of one cone, as each of the ends is a half cone.

When the pile shape is flattened, different, or irregular, profiles and cross sections are taken in the manner described in Chapter 8.

Digging Factors. The digging qualities of a soil are of great importance in estimating. If blasting is required, expenses are increased five times or more, with the extra costs per yard increasing if the quantities are small, or if precautions must be taken against damaging property.

Hard soil that can be barely dug without blasting will also prove expensive, in the terms of slower production, and increased breakage of equipment. It may require the purchase or rental of special or larger machines.

Wet digging requires working from above with hoes or draglines; may call for expensive drainage or pumping, and will cause mud difficulties at the dump. Operation on wet or muddy pit floors may require the use of tracked hauling units instead of rubber tired, with resultant drop in speed; or substitution of all wheel drive for conventional trucks.

Wet conditions may also make necessary the building of temporary roads of corduroy, crushed rock, or gravel.

If boulders are numerous, digging will be hard; there may be a problem of loading stone that is too large to dump through truck tail gates; and, in any event, time will be wasted in separating boulders from soil, either at the bank or on the fill, and in piling, blasting, or working around those

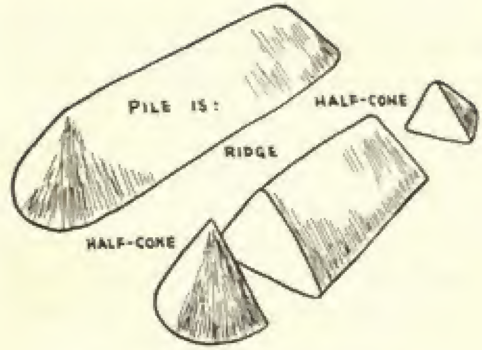


Fig. 11-3. Pile measurement

which are too big or heavy to lift or haul.

Ledge outcrops in a pit floor complicate drainage and make haul roads rough.

Deep cuts which require benching involve more planning and systematic work and probable lost time than straight digging.

The amount of swell of the soil and rock when dug will affect the capacity of hauling units in bank yards, unless such steep grades must be climbed that weight is a more critical factor than bulk.

In scraper digging, the presence of a lubricating material in the soil may make possible bigger or quicker loads. Slippery surfaces, however, decrease production, particularly with rubber tired prime movers.

Fills. Trucked fill placed in thin layers requires more or larger dozers for spreading than when in high lifts. Even if no rollers are used, compaction and rain resistance will be improved because of better vertical distribution of the weight of the hauling units. If rollers are used, the thin layers will have more total surface to be treated, but compaction may be secured with lighter machines, or with fewer passes on each level.

When the spreading dozer is oversize for the quantity of dirt being trucked, the extra cost of thin spreading is negligible.

Scrapers naturally spread in thin layers, so depth requirements are more readily met.

Clean dry sand or gravel may not afford enough traction for trucks so that watering or adding thin layers of loam fill may be necessary.

Production. Most estimators are familiar with the output of the machines to be used on the job. Allowance must be made for special conditions that will slow the machine. These may be water, cramped working area, unexpected changes in the character of the soil, or soft haul roads.

If a relatively unfamiliar machine is to be brought or hired for a job, its production can be studied in the manner indicated in Chapter 3.

Small jobs are often estimated on an average time basis. A hoe or a dozer may be able to dig small house cellars in three to six hours. A contractor specializing in this work may figure that the machine is usually tied up for about a day on such a job, and base his rates accordingly. Estimates may be given on a yardage basis without inspection, upon the customer's assurance that the site is clear and workable, and with the understanding that an additional charge could be made if it is not, or if rock or other special conditions require extra work.

Sequences. Excavation or grading projects often involve a sequence of two or more operations. Sufficient delay in one of them will slow or stop work on those which follow it. Increase in the number of operations makes the final ones more subject to delay. If each step in a series is followed closely by the next, through physical necessity, or haste, the possibility of continuing some work after a breakdown is reduced.

As an example, in laying subsurface drains, a ditch is dug, tile is laid in it, and the ditch is refilled. If the tile is laid and the ditch backfilled immediately behind the ditcher, it cannot even stop for fuel without making the tiling crew and the dozer idle. Any delay in the supplying or the placing of tile will shut down the dozer and, if the ditch is likely to cave, the ditcher as well.

If tile is supplied by truck as required, or a little ahead of use, truck breakdown will stop work quickly. On the other hand, if several hours' supply are laid out along the ditch line, work can continue while the truck is repaired or replaced.

If the ground will permit leaving open ditches, the ditcher may keep several hours ahead of the tiling crew, and the dozer work a long distance behind it so that only a major breakdown will stop more than the unit affected.

In shovel loading, the sequence is digging, hauling, and spreading. If the shovel stops, the job stops. If a truck stops, shovel and dozer work are usually slowed. If the dozer quits, work may shut down after a few loads, or continue some time, depending on dumping conditions.

If two shovels and two dozers are working, complete stoppage is much less likely, although there is an increase in the likelihood of slowdowns.

Slowing or stopping of a job increases the contractor's cost, especially when there is no other work to which machinery can be shifted for the time involved. Fixed expenses continue, and part or all of the payroll. The effect on contracts involving penalties for failure to finish on schedule may be even more serious.

Bottlenecks are another hazard of sequences. Any machine, or any operation, which is slower than those preceding and following it, will set the pace, or the lag, for the whole job, until the condition is corrected. This situation may arise through improper selection of a machine, delivery of the wrong size or type, mechanical or digging difficulties, man shortage, lack of skill, or mistakes in figuring.

In making an estimate, sequences should be studied carefully and allowance made for the probable delays.

Rush Jobs. Rush jobs usually involve

very close sequences to such an extent that machines and men are so on top of each other that a great deal of time is wasted, even if no breakdowns or serious tieups occur. An extra charge should be made to cover this inefficiency.

Another type of rush which is frequently experienced is that a customer, often a home owner or building contractor, will demand that machinery be sent over immediately to backfill and grade around a house, dig ditches, or perform other work required to obtain a payment on a building mortgage, or to make the house look attractive to possible buyers on a week end.

If such a call is answered promptly without investigation, it will all too often be found that the site is not in workable condition. Perhaps the whole area is cluttered with piles of sand, gravel, bricks, and lumber; or the foundation has not been painted with waterproofing, nor the scaffolding removed; or neither the boss nor the plans can be found.

The contractor usually does not have the men or the information necessary to clean things up, or figure what to do. Using valuable supplies for fill, or working in the wrong place, does not lead to friendly customer relations, nor does charging time for the machinery while it is parked waiting for a chance to work.

It sometimes seems that the owner's resentment of mistakes or lost time arising from such negligence on his part, increases with the extent of his fault.

On one such job, a contractor was induced to take a backhoe off a job just long enough to ditch for a septic tank and field at a house whose owner was to be there at eight in the morning with the plans. He did not appear. The contractor wanted to get back to the other job, so he went to the Board of Health, got specifications for the work, and dug for a tank and 240 feet of field—all deep ditching in hardpan.

That night the owner was very angry as he was sure that he had told the contractor that he had received a special dispensation to use only 100 feet of field. He not only did not want to pay for the surplus ditch—he wanted damages for the field that was dug up. Eventually, after much argument, he made partial payment.

Weather. No one can predict the weather with any certainty, but anyone can make a guess according to climate and season.

Appropriate consideration should be given to the possibility of bad weather that may consist of rain, snow, heat, cold, wind, dust, or other factors. Any unfavorable condition will probably increase costs and time requirement.

The effect of rain may be to stop work only while it is falling, or for some time afterward. Pervious soil, proper pit drainage, well maintained haul roads, and compacted fills shorten or eliminate the waiting period for mud to dry.

If the work must continue in spite of rain, machinery should be provided with cabs, and, on average soils, a liberal allowance should be made for crusher rock or gravel to keep vehicles out of the mud.

Other factors in estimating are listed in Chapters 3 and 8 and in the Appendix.

CONTRACTS

A large proportion of excavation is done under contract calling for a fixed payment for certain specified work. Provision may also be made for increased payment for certain difficulties which may arise in doing the work, or for additional work not in the contract.

Contracts are also let on a yardage or other piece work basis, and on cost plus a fixed fee or percentage of cost profit.

Large contracts should be in writing and should be carefully studied. Small ones may be verbal.

Lump Sum. This type of contract is suitable for jobs where all the important factors which will affect the work are known.

Under suitable circumstances, this is the most satisfactory type of contract. It relieves the contractor of considerable measurement, classification, timekeeping, and bookkeeping; and the customer the necessity of watching the contractor's every move. Inspection is still required, however, to assure cuts to proper dimension, accurate grades, and proper construction, compaction, and finishing where specified.

Unless careful engineering investigations are made of the site, such contracts may result in disagreeable surprises for either party. The owner may find that he has paid blasting prices for large volumes of rock that is readily broken out by a shovel; or for removal of valuable material which could have been dug at a profit. The contractor may find himself digging rock where he looked for loam, or installing pumps where he thought he would be high and dry.

A contract which is turning out disastrously for the contractor can sometimes be re-negotiated, but this is largely dependent on the good will and generosity of the owner. The contractor can demand an extra payment only if the unfavorable conditions were known to, and concealed by, the owner; or where the owner withheld information which would have enabled the contractor to anticipate the difficulties.

Lump sum bids require skill, good judgment, and occasionally second sight, on the part of the estimator.

Per Yard Bids. Excavating contracts are often let on a basis of a fixed price per yard for each of two or more classes of digging. The most usual division is into dirt —material which can be dug fairly readily by the size shovel normally used in such work—and rock—material which requires blasting before digging. This classification may put clay formations in the rock class, and rotten rock in the dirt category; but in general, it is fairer than classifying by geologic structure.

Except on small or special operations, payment is for bank yards. The ground is measured before work starts, again when rock is laid bare, and finally when the cut is finished. Boulders are measured individually as they are freed from the bank.

In rock cuts, payment may also be varied according to the position of material removed. Full price may be paid inside the slope or side lines, a lesser price for moderate overbreak, and nothing for excessive overcutting.

Two or more prices may be quoted for varying distances of haul. A common cause for this is the use of selected borrow from pits whose capacity is not fully known.

Hauls up to a certain distance may be figured as part of excavating costs, and extra payment made for carrying it longer distances. The excess is called overhaul or paid haul.

Cost-Plus. When important conditions of the job are unknown, the contract may be made on a cost-plus basis. The contractor will then have all his costs in doing the work repaid, and will receive either a fixed fee or a percentage of his costs in addition. This type of contract is most often let in government or other work where haste prevents thorough investigation of the site, or plans are subject to change during operations.

The fixed fee basis is appropriate where the total amount of work can be estimated with fair accuracy, and the percentage where changes and extras can make up a substantial part of the job. The latter system is subject to grave abuses, as mistakes which add to the cost will increase the profit, so that inefficiency is rewarded.

A serious cost-plus difficulty is that it is apt to lead the customer to interfere with the contractor's policies and management on the job. This effort to lower costs is liable to be of the penny-wise pound-foolish variety, and increases expenses more often than it reduces them.

It is important for the contractor to

include all indirect as well as direct costs in this type of bid.

A variation of cost-plus is a bid listing hourly or daily rates for all machines, services, and personnel to be employed on the job. The contractor figures his profit on each unit into the price charged for it.

Jokers. Many contracts are tricky and can be used to make the contractor do his work for part pay, or to take the responsibility for conditions beyond his control.

It is customary to make payments on account on jobs which take over a few weeks to complete, so that the contractor will not have to scratch for payroll and immediate expense money. In many types of work, it is usual for the owner to withhold a percentage, which may range from five to fifty percent of the value of work performed, as security for completion of the job and fulfillment of any guarantees.

Such contracts may leave the owner the option of not completing the job, thus withholding final payment indefinitely. For example, a contractor might bid on a development job of installing sewers, backfilling the ditches, laying gravel roads, and then blacktopping. This is one job, and 10 percent withheld from payments is not due until the blacktop is completed.

But the developer can sell his houses when he has the gravel in. He may lack the money to put on blacktop, or just figure it is a good idea not to do it, and hold on to the percentage. He may be able to do this under the contract, unless it specifies that each operation calls for a separate final settlement, or that all work may be performed in proper sequence, without specific authorization.

Another trick is to exact a guarantee of quality while specifying material or methods which may be sub-quality. If roads are to be constructed of bank-run gravel from a developer's pit, the contractor should not guarantee that they will be passable after a rain unless he is given the option of rejecting part or all of the material if it is substandard, and importing better gravel at additional cost.

On contracts which call for penalties for failure to complete by a certain date, the contractor should be protected against delays caused by the owner. These may include failure to complete prior operations, or to remove surplus material left from them; or not supplying plans, grade stakes, work permits, or access to property on time.

The contractor should also protect himself against shortage of materials, by means of delay-caused-by-circumstances-beyond-control clauses, option of substituting available for unavailable items, or both.

However, the greatest losses to contractors occur because of forgetting to leave a loophole for possible underground conditions. The big three are rock, mud, and flowing water, and one or all of them can crop up in most unexpected places.

WORKING BY THE HOUR

Excavating contractors may avoid some of the pitfalls of estimating by working on fixed prices charged by the hour, day, week, or month for their machinery. When working for another contractor, or under supervision of an engineer, no estimating may be required.

Prices obtained are determined primarily by the size and type of machine, but are also affected by the duration of the work, whether it is hard or easy, probable amount of idle time on the job, and the amount of supervision required.

In small private jobs, an approximate estimate of total cost is usually required, even when working by the hour. While this should not include a guarantee of doing the work within the figure stated, it is good business to have it fairly accurate.

Contracts vs. Hourly Work. A contract to perform a job for a fixed sum of money must be based on a thorough understand-

ing of the nature and finish of the work by both the owner and the contractor.

If good faith exists on both sides, it is usually easy to arrange a simple contract between contractors, or between a contractor and a man who is familiar with excavation and grading.

In making arrangements with persons of little or no knowledge of excavating procedures, the greatest care should be taken to explain both what will be done and what will not be done.

If conditions are such that the contractor cannot readily tell the amount, kind, or conditions of excavation; if the amount of work to be done has not been determined; if it is not practical to clearly define the extent of the work and the condition in which it is to be left; or if the job is to be done a little at a time, as equipment or funds are available, the cost-plus or hourly basis will probably be the most satisfactory.

There are several standards of hourly work and ways to keep track of it.

A working hour may be the time that the machine is actively doing the job; the time it is present on the job and ready to work, or all the working time during which it is in the possession of the customer.

Bare Rentals. When a machine is rented bare—without operator, fuel, or maintenance—the number of hours in the work day are usually specified, and the charge made by the day, week, or month. If the machine is worked overtime, extra payment is made on a proportionate basis. If it does not work the number of hours allowed, full charge will be made except under special conditions. Most firms renting equipment will make allowances for time lost through long breakdowns, excessive bad weather, or strikes or material shortages; but the conditions under which such allowances will be made should be clearly understood in advance.

In general, the lessee of bare equipment is responsible for all maintenance and repair, and is required to return the machine in as good running condition as he received it. However, if a machine has a major breakdown shortly after being put to work of a nature that cannot be blamed on abuse or carelessness, the owner may stand all or part of the repair expense. Such repairs should definitely be the responsibility of the owner if the breakdown is in parts known to be defective at the start of the rental period.

Rental with Operator. When equipment is rented with an operator, its owner usually pays all expenses, including fuel, lubricants, and repairs. Occasionally, the lessee may furnish fuel if he can do so more conveniently than the owner.

Pay for time during which the machine is stuck in mud is usually on the lessee, as it is a mishap caused by job conditions. However, if the fault lies with a disobedient or careless operator, or if the owner has warranted that the machine will not get stuck on that job, payment may be withheld.

The machine is not paid for time lost because of mechanical failure or absence of the operator. However, stops for adjustments, minor repairs, fueling, lubrication, or cigarettes, which average less than ten minutes an hour, may be considered working time if agreement is made to that effect.

Timing. Working or pay time may be taken from readings of electric hour meters, which register the time the engine is running; from mechanical counters which register engine revolutions in terms of hours of wide-open operation; from special checking by a foreman or timekeeper, from the lessee's job time sheets, or from the owner's pay roll records.

On operator work, it is good practice to check time daily and have the customer sign a ticket for it.

Timing by hour meter leads to owners' operators keeping the engine running, whether it is needed or not. Many jobs in-

volve substantial amounts of waiting time, during which noise and wear would be reduced by stopping the engine, but this action by the operator would penalize his employer and possibly himself.

Hour meters should be checked frequently as they may become disconnected, stop, or become inaccurate.

Engine revolution counters are more accurate, and seldom get out of order, but when used as a pay basis, offer the added disadvantage of placing a premium on running the engine at full throttle at all times. This may make it difficult to do precise or fine work and will cause excessive wear, waste, and noise.

Bare Rental Prices. The Associated Equipment Distributors, 30 East Cedar St., Chicago 11, Illinois, publish every other year a "Compilation of Rental Rates for Construction Equipment." Some representative tables from the 1953 edition are reproduced in Figures 11-4 and 11-5.

The Foreword of this Compilation reads in part:

"Rental rates vary greatly throughout the United States, depending on local practices and conditions, and upon the use to which the equipment is placed. The Compilation of Rental Rates in no way reflects the "going rate" in any area, and cannot be so used. The rates set forth are national averages compiled from individual companies.

"It is emphasized that this compilation is published for informational purposes only, and is not intended to suggest or to influence rates or terms of rental.

". . . conditions may cause major changes in the pattern of rental rates and practices during the interim between publications."

Rental rates are strongly influenced by supply and demand. Companies that are in the business steadily usually maintain prices, but owners who rent occasionally may charge what the traffic will bear.

Casual renters are influenced also by the amount of use they may have for a machine during the rental period, and by the state of their bank accounts.

It should be noted that a single machine might have to be looked up in several places to get the full price. Separate charges are made for a dragline and its bucket. A winch-equipped bulldozer would rate the price of a tractor plus a winch plus a dozer attachment.

In spite of the difficulty of applying the figures to actual rentals, the Compilation is very useful to contractors as a quick guide to relative costs and values of different types and sizes.

It may also be useful in convincing suspicious customers that excavation equipment does earn good pay.

MACHINERY SELECTION

Purchase of a machine, whether new or used, involves consideration of the type and amount of work in hand and expected, price and availability of suitable models, as well as operator skills, work habits and personal preference.

Size. The arguments about machine size can appropriately be restated here. A big excavator is more costly to buy and to move, and requires more working space. It will dig more dirt in a given time, will handle harder and coarser formations, and will show a lower cost per yard if it has space to work, and is teamed with other equipment of proper size. It is harder to service and repair because of volume of fuel and lubricants used, and weight of parts. It gets stuck more easily and seriously in soft spots, but seldom hangs up on rough ground.

When space is restricted, ground is soft, or other conditions are unfavorable to the large unit, a small machine may not only work at a lower cost per yard, but may handle a larger volume as well.

Under conditions of equipment short-

Shovels Back Hoes — Dragline

DIPPER INCLUDED (WITHOUT BUCKET)

GASOLINE-ENGINE-DRIVEN

Capacity of Machine when used as a Power Shovel	Shovels, Back Hoes: Per Month	Per Week	Per Day	Dragline: Per Month	Per Week	Per Day
⅜ cubic yard	$640.00	$214.00	$69.25	$604.00	$200.00	$66.75
½ cubic yard	807.00	270.00	87.00	766.00	260.00	83.00
⅝ cubic yard	817.00	275.00	87.75	813.00	275.00	87.50
¾ cubic yard	1044.00	350.00	111.00	1004.00	338.00	109.00
1 cubic yard	1183.00	395.00	132.00	1155.00	408.00	130.00
2 cubic yards	2300.00	779.00	261.00	2139.00	702.00	233.00
2½ cubic yards	3138.00	1064.00	353.00	2903.00	962.00	319.00

DIESEL-ENGINE-DRIVEN

Capacity of Machine when used as a Power Shovel	Shovels, Back Hoes: Per Month	Per Week	Per Day	Dragline: Per Month	Per Week	Per Day
⅜ cubic yard	$760.00	$253.00	$84.25	$695.00	$236.00	$77.75
½ cubic yard	917.00	313.00	99.25	868.00	295.00	95.00
⅝ cubic yard	997.00	335.00	111.00	888.00	302.00	100.00
¾ cubic yard	1191.00	401.00	128.00	1134.00	378.00	121.00
1 cubic yard	1481.00	501.00	160.00	1331.00	453.00	146.00
2 cubic yards	2982.00	988.00	319.00	2661.00	883.00	287.00
2½ cubic yards	3753.00	1239.00	412.00	3332.00	1122.00	378.00
3 cubic yards	4196.00	1394.00	462.00	3896.00	1300.00	429.00
3½ cubic yards	4699.00	1587.00	527.00	4353.00	1442.00	452.00
4 cubic yards				6400.00	2150.00	620.00
5 cubic yards				7500.00	2500.00	750.00
6 cubic yards				9000.00	3000.00	900.00

Tractor Trailer Units

2-WHEEL TRACTOR WITH 2-WHEEL CABLE SCRAPER

Tractor		Scraper						
		Struck		Heaped				
From, not including Brake HP	To and including Brake HP	From, not including (cu. yds.)	To and including (cu. yds.)	From, not including (cu. yds.)	To and including (cu. yds.)	Per Month	Per Week	Per Day
100	125	4.5	6	6.5	8	$1515.00	$516.00	$160.00
160	186	8.5	11	11.5	14	2200.00	794.00	270.00
195	225	13.5	15.5	17	19	2477.00	826.00	285.00
235	280	13.5	15.5	17	20	2883.00	861.00	339.00

4-WHEEL TRACTOR WITH CABLE SCRAPER

103-111 Gas, incl.	5.0	8.75	7.5	11.0	$1369.00	$ 447.00	$156.00
103-111 Diesel, incl.	5.0	8.75	7.5	11.0	1500.00	510.00	170.00
94-102 Diesel, incl.	6.0	10.5	9.0	13.0	862.00	442.00	148.00
103-111 Gas, incl.	8.75	11.0	11.0	14.0	1551.00	527.00	175.00
103-111 Diesel, incl.	8.75	11.0	11.0	14.0	1897.00	662.00	222.00
70- 95 Gas, incl.	5.5	8.5	6.5	9.5	1138.00	388.00	130.00
70- 95 Diesel, incl.	5.5	8.5	6.5	9.5	1340.00	479.00	160.00
115 Diesel	6.5	8.3	8.5	10.5	1501.00	495.00	165.00
115 Diesel	9.5	12.0	11.5	15.0	1525.00	508.00	170.00
165-186 Diesel, incl.	8.0	11.0	11.0	14.0	2509.00	941.00	314.00
275 Diesel	14.5	18.0	17.5	23.0	3075.00	1101.00	392.00
300 Diesel	13.0	15.5	16.5	19.0	3597.00	1349.00	450.00

Courtesy of Associated Equipment Distributors

Fig. 11-4. Average rental rates for shovels and self-powered scrapers, early 1953

age, the large unit often has a proportionately higher resale value than the small one.

There is a steady trend toward the use of bigger equipment.

New or Used? Some successful contractors buy nothing but new equipment, while others buy only used pieces. In general, but not always, a new machine will have less mechanical trouble, and will receive better service from the dealer. It is more costly in purchase price, and in percentage of loss when sold. It has advertising or prestige value. It may be difficult or impossible to

Tractors, DIESEL

CRAWLER

(brake horsepower) From	To	Per Month	Per Week	Per Day
20	33	$ 369.00	$128.00	$ 41.00
33	41	462.00	150.00	50.25
41	46	514.00	168.00	55.50
46	52	557.00	188.00	62.75
52	62	668.00	221.00	72.00
62	72	791.00	259.00	83.75
72	89	890.00	299.00	94.00
89	100	1027.00	342.00	110.00
100	115	1157.00	385.00	115.00
115	135	1209.00	406.00	123.00
135	150	1648.00	558.00	175.00

4-WHEEL, RUBBER-TIRED

38	47	$ 260.00	$ 91.00	$ 28.50
47	50	301.00	100.00	35.00
50	60	342.00	115.00	39.00
60	100	755.00	264.00	88.00
100	115	1019.00	349.00	107.00
115	125	1170.00	390.00	130.00
125	140	1214.00	410.00	135.00
140	180	1225.00	418.00	139.00
180	195	1648.00	572.00	189.00
195	250	1637.00	561.00	187.00
250	290	1660.00	587.00	196.00

2-WHEEL, RUBBER-TIRED

80	100	$ 987.00	$332.00	$111.00
100	125	1211.00	422.00	138.00
125	165	1352.00	428.00	143.00
165	180	1863.00	619.00	207.00
180	195	1950.00	656.00	215.00
195	220	2156.00	730.00	244.00

Tractor Attachments

added to above rates.

Bulldozers

—	42	$132.00	$45.50	$15.00
42	66	172.00	55.50	18.25
66	89	197.00	64.75	21.00
89	135	226.00	75.50	24.75
135	150	284.00	90.75	29.75

Angledozers

—	42	$150.00	$ 50.25	$16.50
42	66	188.00	62.75	20.25
66	89	218.00	73.50	23.50
89	135	257.00	84.75	27.50
135	150	315.00	105.00	33.50

Buckets

CLAMSHELL

	Per Month	Per Week	Per Day
1/4 cubic yard	$ 82.50	$ 28.00	$ 9.10
3/8 cubic yard	90.75	30.25	9.75
1/2 cubic yard	104.00	35.25	11.00
5/8 cubic yard	112.00	37.50	12.00
3/4 cubic yard	129.00	43.75	14.00
1 cubic yard	147.00	48.50	16.00
1 1/4 cubic yards	173.00	56.75	18.75
1 1/2 cubic yards	194.00	64.00	21.00
1 3/4 cubic yards	210.00	66.75	22.00
2 cubic yards	225.00	71.50	23.50
2 1/4 cubic yards	279.00	92.25	30.50
2 1/2 cubic yards	302.00	98.50	32.50
3 cubic yards	365.00	121.00	39.75
4 cubic yards	446.00	151.00	50.50

DRAGLINE

3/8 cubic yard	$ 61.75	$21.25	$ 7.10
1/2 cubic yard	79.00	24.50	8.05
5/8 cubic yard	83.75	29.00	9.75
3/4 cubic yard	95.25	33.00	11.00
1 cubic yard	111.00	37.75	12.75
1 1/4 cubic yards	124.00	41.25	13.75
1 1/2 cubic yards	139.00	45.75	15.00
1 3/4 cubic yards	149.00	49.00	16.25
2 cubic yards	162.00	53.50	17.75
2 1/4 cubic yards	166.00	54.75	18.00
2 1/2 cubic yards	181.00	60.00	19.75
3 cubic yards	196.00	64.75	21.00
3 1/2 cubic yards	210.00	68.00	22.50
4 cubic yards	217.00	71.50	23.75

Pumps

CENTRIFUGAL (Self-priming)

GASOLINE

	Per Month	Per Week	Per Day
1 1/2-inch 4 M	$ 44.75	$ 15.50	$ 5.00
2-inch 7 to 10 M	54.75	18.75	6.00
3-inch 15 to 20 M	68.75	23.50	7.65
4-inch 30 to 40 M	106.00	36.25	11.75
6-inch 75 to 90 M	166.00	54.75	18.50
8-inch 125 M	262.00	86.50	30.50
10-inch 175 to 225 M	303.00	98.75	33.00

DIESEL

6-inch 75 to 90 M	$228.00	$ 76.25	$ 23.75
8-inch 125 M	394.00	118.00	43.25
10-inch 175 to 225 M	473.00	134.00	50.00

Courtesy of Associated Equipment Distributors

Fig. 11-5. Average rental rates for miscellaneous equipment, early 1953

secure in the make, size, and model wanted within a reasonable time.

A purchaser of used equipment should have a good knowledge of mechanical condition and current values, and must be alert for liquidations and other forced sales where good values can be obtained. Considerable time may be required to find a particular make and model at a good price, and haste may make it necessary to pay too much. On the average, repairs will be more costly and service less satisfactory than on new units.

The expert buyer of used machinery is

often able to sell his purchases at a profit, sometimes obtaining considerable work from them first. The average buyer, however, will seldom accomplish this, and is liable to be stuck with worthless machines now and then.

Rubber vs. Tracks. Rubber mountings usually provide more mobility and less traction and flotation than tracks. They offer the advantage of working over pavements and hard obstructions without damage, and can move over public roads without use of trailers. With some exceptions, they are not as maneuverable in close quarters, and they are more often slowed or stopped by soft or slippery footing.

Tracks are better in the cut and at the bank, but tires are superior on the move.

Big tires are given credit for adding to operator comfort. They help at crawler speeds, but fast moving wheeled equipment on uneven ground is very rough on the operator, and often calls for a safety belt to keep him in, and a motorcycle belt or corset to hold him together.

The contractor planning to use such machines must figure on grading equipment to keep haul routes smooth.

If rubber tired equipment is selected because of its ability to travel on roads without a trailer, the cost of licensing and insurance should be investigated. Some states license heavy equipment for a set fee of a few dollars. Others charge the same rates per pound or per horsepower as for trucks, which, on heavy equipment, may be a large sum.

Technicalities involved in obtaining permits to move over-width machines may be so tedious as to interfere with their use. This is a question not only of the law but of the attitude of local authorities toward its enforcement.

DEFECTS IN EQUIPMENT

Criticism. Manufacturers of heavy equipment have reason to be proud of their products. Any earthmover is an intricate, ingenious, and practical machine, and is the product of years of research, testing, and trial and error.

Under such circumstances, criticism may seem in questionable taste. But the operator, the mechanic, the contractor, and the distributor who must keep them satisfied all know that most machines are far from perfect, and that many of their failings seem both stupid and unnecessary.

The contractor cannot take it for granted that a piece of equipment is either well designed or well built, even if it is produced by a company with an old and honored name and a currently good reputation. Black sheep are as common in good families as in bad.

Few earthmoving machines are ready to work with full efficiency when they leave the factory. Correcting omissions and built-in mistakes of the manufacturer is one of the major headaches of conscientious equipment distributors. Necessary work ranges from simple but costly procedures such as hardface welding on too-soft teeth and edges to elaborate reconstruction and replacements. They may receive partial compensation from the factory for such work, but often they do not.

Causes. Difficulty with new equipment can arise from poor design, poor workmanship or material, or from both. In regard to the first, it often seems to the users that if each manufacturer had in his employ one reasonably intelligent and open minded high school boy with authority to pass on new models, most of these troubles could be avoided. The writer is inclined to agree.

Many defects indicate a serious gap between desk and drafting room theory and the hard facts of working on the job. The question of why theory cannot grow up to include the facts is interesting.

One clue is that in the course of the years a contractor might see almost every

kind of manufacturer's representative, including salesmen to bother him when he is busy, trouble shooters to tell him that he is imagining his difficulties or abusing his machines, and even the president of the company addressing an association meeting. But has any contractor ever been called on at work by a design engineer interested in hearing what is wrong with equipment, and what he would like in new models? Very doubtful.

However, there is no question but what the manufacturer has his problems. Each model is built to a size, weight, and price, and one or more of these limits may prevent inclusion of certain desirable features. Mistakes inevitably occur in translating plans into metal, and when tens of thousands of dollars may be invested in patterns and tools to make a single part the temptation to make the best of its defects is certainly strong.

Some of the more obvious and apparently inexcusable mistakes in a new model arise from field testing. Pilot models are built and used, and various defects show up. Corrections are made, but when production models appear secondary defects are found, due to the altered parts not working in as well as expected. By the time these mistakes are caught hundreds of the machines are at work, and corrections must be made in the field by the distributor organization. Some such errors are inevitable, and as long as they are made good with reasonable promptness, they should not be held against the manufacturer.

However, mistakes in basic design and in partial corrections, together with ordinary defects in material and workmanship, often add up to a machine that costs the contractor more in down time and upset schedules than it produces in work, even without considering the original investment. The promptness and efficiency with which the distributor services the machine,

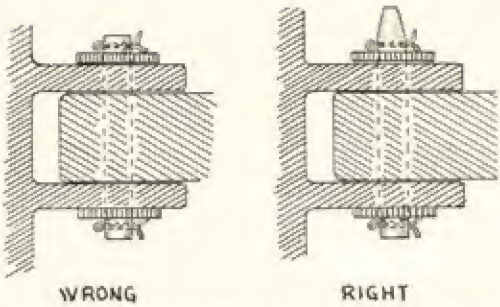


Fig. 11-6. Straight cut and beveled pins

and the vigor with which he presents the owner's case to the manufacturer, are important in determining whether such a "lemon" will constitute a serious loss or just an annoyance.

Each contractor and operator has his own pet peeves about equipment. Those that are listed below are fair samples.

Inconveniences. The standard method of fastening a detachable rig, such as shovel front end or a dozer shovel bucket, to the main machine is by knockout pins. When the attachment is being installed each pin must be put through three or more holes in heavy pieces, as in Figure 11-6. If the pin is cut straight across the ends, the parts must be exactly in line. However, if one end of the pin is extended and tapered it can correct considerable differences in alignment as it is driven through. The pin must of course be of hard steel so that it will keep its surface intact.

Properly beveled pins will save from one quarter to three quarters of the time needed to install almost any kind of a rig, and may be absolutely necessary to a man working alone. All mechanics, operators, and factory field men know this, but production lines continue to put out straight cut pins, or those with practically no bevel.

When a cable is being threaded around a boxed-in sheave, as in Figure 11-7, it tends to push against the back of the box and stop there, so that crimping and fishing are needed to get it around. This annoying difficulty is easily eliminated by

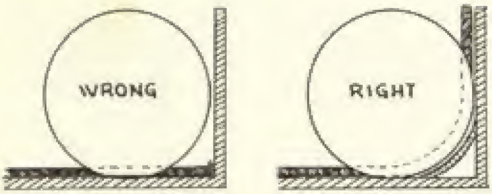


Fig. 11-7. Boxed-in sheave

installing a curved plate which will direct the cable the way it should go.

Such guide plates have been in use for at least 50 years, but equipment is still coming off the assembly lines without them.

Unfinished Designs. A four wheel drive bulldozer was delivered to the writer as a rental. This model had been introduced about a year before, and was a brilliant, progressive piece of engineering that included many basic advances that are now widely copied. But if the blade was raised all the way, either by the cable or by being kicked up by its load, a sharp edge would pin the cable against its shallow-groove pulley and cut four of its six strands as neatly as a cable cutter. Also, if the cable was allowed to get at all slack it would spill off the side of the drum and get in trouble.

Correction of these defects would have cost the manufacturer less than five dollars, although it took a welder over four hours in the field. The factory was notified of the difficulties and of the simple changes that cured them, but for the next two years it continued to put out the machines in the same condition. The distributor made a routine job of fixing them over before delivery, as he found it was cheaper than answering complaints and supplying free cables and extra hours of instruction.

An otherwise excellent one yard shovel dozer was put on the market with only eight ¾ inch capscrews to try to hold its three tons of live weight down on the tractor. Of course they stretched and broke about as fast as they could be replaced. Distributors who liked to see their customers get steady work out of the machines were forced to reinforce the connections by welding on heavy plate.

After a long time the factory worked out a new method involving heavy tapered bolts that was absolutely secure. Too secure, in fact, because there was no way to get it apart after it was in service for a while.

A revolving shovel that was supposed to be able to handle a ¾ yard dragline bucket on a 40 foot boom was produced for years with only four 1¼ inch bolts to fasten the turntable to the undercarriage. This manufacturer was sufficiently aware of the mistake to do free welding on one broken undercarriage after 30 months of service, but insisted that it be done the factory way instead of the right way.

This breakup cost the customer over $1000 to take the shovel apart for the job, put it back together, and hire a substitute machine, and the base broke up again in two years. New shovels of this model now have 12 bolts and heavier bracing, improvements that any mechanic would have insisted on in the first place.

Power Controls. Power controls offer an interesting study in both manufacturers' and operators' psychology. For years the operator was supposed to be (and pretty much had to be) a tough beefy individual who could pull and push and haul on clumsy levers, crank heavy engines, balance fuel cans and funnels in improbable places, and do it every day, ten hours a day. Little attention was shown to the problem of making the machines easy to run and service.

However, the operators apparently thrived. The first crawler tractors to feature electric starters, reasonably easy controls, and other conveniences were considered effeminate and unworthy of serious comparison to the good old brutes, and

progressive models of other excavators did about as badly.

But the easy way is gaining popularity, and power controls, easy-shift transmissions, and other conveniences are now offered in great variety. However, many of them are of very questionable quality. There is (or was very recently) a small shovel with air controls. The valves were poorly balanced and jerky, and the operating levers were backed by such stiff springs that it took over twice the effort to open the air valves than it did to engage the clutches and brakes mechanically in the previous model.

Another prize package is a crawler tractor with hydraulic booster for the steering clutches, the pump for which is in the transmission. When the master clutch is disengaged, so is the booster. If the machine is moving the steering clutches take less than a five pound pull, if it is stopped, over sixty pounds. And in tight quarters a man often needs to pull a steering clutch before he starts moving. The main clutch and the brakes have no booster.

Easy-shift transmissions have found their place even in big crawler tractors. However, if the manufacturer provides a torque converter so that only two forward speeds are needed, he may go back to the primitive bash-and-clash shift which with these heavy gears takes far too much of the operator's strength and of the machine's excessively expensive time. The contrast between the miraculously smooth automatic shifting of the torque converter through an infinite range of speeds, and the crude, heavy, work wasting forward-reverse gear shift behind it should appall any designer, particularly as smooth and rugged reversing clutches have been available for many years.

Fortunately the torque converter is now teamed more and more often with transmissions that clutch-shift on the move in either direction without effort, noise, or delay. Some of these more modern machines have their troubles, particularly in too-sudden engagement of air clutches that may shock and damage the power train, but their production is always far higher than the old fashioned constructions of similar weight and power, and they are on the right road.

Electric Starter. The electric starter was standard equipment on most automobiles by the middle twenties, and might reasonably have been expected to appear in construction machinery at the same time. However, it took twenty years and a mechanized world war to make it universally available even as optional equipment.

There never could have been any serious argument about the desirability of electric starting for any machine able to carry the extra weight and cost. It means more work hours, particularly in cold and wet weather, and an end to broken wrists and strained backs from cranking. It is simple, and it is cheap compared with the cost of a tractor or a shovel. Yet its adoption lagged for a generation.

Basic Shortcomings. A very common mistake in design is the use of an undersized clutch that requires frequent adjustment and replacement. The experienced repairman can frequently spot such units on the showroom floor. Simple common sense indicates that if an engine is made more powerful, if a tractor is made heavier, or if mounted attachments involve more clutch wear (for example, stepping up from a bulldozer to a shovel dozer), then the clutch must be increased in capacity. But it often is not.

A shovel dozer must exert its maximum lift at a low level in order to break its loaded bucket out of the ground. One of the earliest designs included a bucket that could have its lip rotated upward from digging position, giving a powerful prying effect with the back of the bucket as a fulcrum. Yet not only was this excellent

construction ignored for years by all the big companies, but one of them after years of research produced a machine in which the hoist rams and the lift arms were nearly parallel when down, so that hoist leverage was at a minimum at breakout point and became steadily stronger as it was lifted through the air.

On ordinary dump truck body can be raised to a maximum angle of around 50 degrees, because it comes down by gravity, and greater lift might overbalance it so that it could not be lowered. This slope is usually adequate for easy dumping on the level, but works very badly with sticky loads and when backing up a grade.

Big off the road trucks have power both up and down in their hoists, and can raise to 70 degrees or more. Recent inquiry showed that this excellent and much needed feature was not available even as an extra price option on any popular small truck body, even though the design and construction problems are slight.

The dump hoist pump is usually driven from the transmission, so that it does not operate when the clutch is down. The valve is likely to be jerky, so that it cannot be held partially open and the body will be lifted at full speed or not at all. In ordinary dumping such features are all right, but when a driver is trying to spread a load, or to dump only part of it, they combine to give him a very hard time and produce a sloppy job. Hydraulic pumps could be driven directly by the engine, and valves could readily be made to open gradually and smoothly, so that the driver could be given exact control of the hoist.

Hydraulics. Hydraulic power transmission has striking advantages over cable and mechanical linkages for close coupled attachments. It may be expected to continue to widen its applications and to displace its competition. However, much of its progress is made in spite of rather than because of the efforts of many designers and manufacturers of hydraulic equipment.

A hydraulic valve can and should offer a perfectly smooth transition from neutral or hold to fully open position. There are few applications where the resulting control of speed is not desirable. Also, such a construction requires excellent balance and therefore provides easy operation. Problems of heating and turbulence can be solved.

Valves that tend to jump from one position to the next, or are so poorly balanced that they are hard to push past certain points, are fatiguing to operate and difficult to control, and give hydraulic systems a bad name. Yet they outnumber the good valves two or three to one.

In the early forties most hydraulic rams had heavy wick packings and compression nuts to prevent oil leakage along the piston rods. These required adjustment only at long intervals, and seldom leaked. They were replaced by the smaller and neater chevron or V-packing, and for a few years lots of equipment had more of its oil outside than inside. Improvements in quality of the packings and chrome plating of piston rods finally stopped the excessive leaking and need for adjustment, so that now these packings are practically as good as the old type. However, the streamlined appearance that was gained is hardly worth the damage to industry prestige suffered during the development period.

Designers of hydraulic equipment tend to be stingy in figuring range of action, on the basis that every inch of potential movement costs either money or power. This economy results in bulldozers that cannot reach down far enough to start cutting a ramp without backing up on a pile nor reach high enough to push over a tree, loaders that can barely get their bucket over the side of a truck, and scarifiers that will not lift out of the way. Undersize pumps and rams work well when the ma-

chine is new, but deteriorate and fail long before really adequate units in the same work.

Fuel Tank. Dirty fuel is one of the chronic troubles of engines. This is particularly important in the excavation industry, as much of the machinery is supplied from drums or cans instead of direct from a pump or tanker. As a result it is difficult to keep the fuel clear of water, dirt, paper, leaves, and other foreign material.

Equipment that stands idle tends to accumulate water in the tank from condensation. Fuel tanks of untreated metal and those which have been inadequately treated may rust and scale, thus contaminating the fuel.

These unwanted and damaging extras are kept out of the carburetor or injectors by one or more filters in the line. Their flow and reservoir capacity is usually small, so that dirty fuel will clog them frequently. Partial clogging results in poor performance which may continue for some time before the cause is found. Cleaning a filter requires stopping the machine.

Foreign material frequently clogs the fuel line between the tank and the filter, usually at an elbow just outside the tank. Such an obstruction can often be temporarily removed by blowing back with air pressure, but eventually the line will have to be removed and cleaned.

Fuel filler holes are often too small to take pour direct from a can, so that a funnel, which is a nuisance and a rich source of dirt, must be used. The filler is often so located that it is difficult or impossible to empty a can into it.

All these troubles could be cured by making the filler opening accessible and 5 or 6 inches in diameter, to permit a man to pour direct from cans, and to reach his hand into the tank. A high grade filter could then be installed on the fuel line inside the tank. The tank bottom would serve as an ample reservoir for trapped water, and could be drained occasionally through a petcock. The filter element could be replaced when necessary through the filler opening. No coarse dirt could get in the lines to plug them, and engine filters would very seldom need servicing.

It is difficult to get a tight seal on a large filler cap. If a slight seepage of fuel around it were objectionable, a smaller size could be used, and a bolted-on cleanout plate installed in the top of the tank.

Millions of dollars worth of machines have limped through unprofitable lives because of trouble with dirty fuel and corroding tanks. They would have done good jobs with this minor change in construction.

CAUSES OF FAILURE

Every year many excavating and general contractors fail, or sustain losses that force them to operate on a reduced scale, or give up. Most of the failures arise from one or more of the following causes:

- Unforeseen price rises.
- Abnormal labor cost.
- Abnormal equipment breakage.
- Death or disability of owner or key men.
- Fire not adequately insured.
- Liability or property damage not adequately insured.
- Poor accident record.
- Failure of subcontractors.
- Adverse weather.
- Unforeseen subsurface difficulties.
- Faulty credit judgment.
- Sudden restriction or withdrawal of credit.
- Unavailability of materials.
- Taking on too much work for financial resources.
- Taking on too much work for adequate supervision.
- Speculation.
- Diversion of funds to non-business use.
- Embezzlement by employees.

Some of these subjects have been discussed previously, others are of a general business nature and are too complex for discussion here.

Two subjects of particular importance to the excavator, however, are accidents and insurance.

ACCIDENTS

Employees should be protected by workmen's compensation insurance. This coverage is usually required by state law, but in any case is a MUST for any employer who is interested in the welfare of his employees, and in his own. Non-employees and property of others should be protected by liability and property damage insurance, lack of which can wipe out a prosperous business overnight. A contractor can protect his own equipment and property with fire and damage insurance.

However, the possession of full insurance does not justify the slightest negligence in regard to accident prevention. For one thing, the best insurance will only pay the more obvious costs. In small accidents that are most common, indirect uninsurable costs may run five times as high as the payments under compensation.

Some of these expenses and losses are:

1. Increase in insurance rates.
2. Payment to injured employee of wages for period too short for compensation.
3. Loss of time of other employees who stop work at the time of the accident and because of it.
4. Time spent by foremen and supervisors in assisting injured man, investigating the cause, selecting and briefing or training another man for the job, and preparing accident reports and attending hearings.
5. Slowdown of job, with possible failure to finish by deadline.
6. Paying full wages to employees who return to work before being capable of performing full duties.
7. Loss of chance for profit on man and his machine.
8. Lowering of morale on the job.
9. Possible interference with work methods by public officials.
10. Unfavorable publicity.

Prevention. The first rule in accident prevention is to use common sense—in laying out a job, assigning machines and personnel to their duties, providing adequate supervision without fussiness, and in setting up sensible and reasonable safety rules.

Too many safety rules may be worse than none. Everyone of us has a limit in the amount of good advice we can absorb, and the limit is often painfully low. It is better to take a few important points at a time, and hammer them home, than to prepare long lists that will neither be read nor remembered.

Rules should be reasonably close to prevailing practice whenever possible, and should aim at greater rather than at lesser evils. A city whose streets are littered with newspapers and garbage should not start a cleanup campaign by arresting men for dropping cigarette butts. (But this is what the biggest city of them all has done.)

Enforcement of safety rules should not be so strict as to cause men to fail to report for first aid for minor accidents, or to lie about the way in which they occurred.

A worker's skill should not be taken for granted. In an emergency an unfamiliar machine might trick an experienced operator into the wrong move. Judgment should be used in giving out ticklish assignments. Training and refresher programs should be given periodically and whenever needed, and reference material on proper operation and procedures should be available.

Good housekeeping is important. Piles of junk, material, litter, boards with projecting nails, carelessly piled bags of ma-

terial or heavy parts, and accumulations of grease and dirt cause accidents directly, and also indirectly by encouraging sloppy work attitudes.

Crowding causes accidents. On a rush job a boss tends to jam as many machines and men into the work area as it will take without bulging. That may mean collisions, and collisions lose time. A man can dig a ditch faster alone than with a helper who hits him on the head with a pick.

Piling Materials. High piles are dangerous piles, except loose material lying at its angle of repose. High piled bags or boxes may look all right, but only until something happens, and that doesn't have to be an earthquake. A truck running into or hooking a pile, or material leaking from a bottom bag, may bring a whole stack down, and the higher they are, the harder they fall.

Piles of bags or pieces of any height should be crosspiled, braced at the ends, and stepped back from the bottom.

In excavating, even a shallow ditch can injure a man seriously by caving, and deep ones are killers. High vertical faces around a cellar excavation might stay up, but it is safer not to trust them. Shore them up, and make sure the shoring is strong enough. Don't just guess, have it designed and inspected by an experienced and careful man.

Barricades. It is not only the workmen who must be kept out of accidents, but also the public. There are sidewalk superintendents who like to watch the work, and are apt to be foolish enough to fall into it if they have the chance. If there is an attractive danger spot, like a cellar excavation, they must be fenced out. Experience has shown that the fence must be strong, and at least seven feet high.

The fence or barricade must be secure itself, so that it will not fall into the excavation, or be left partly in space by a slide. It should have windows or peep holes in it. They build good will for the contractor, and make spectators less likely to move into the very dangerous truck drives that penetrate the fencing.

Barricades, signs, and flares can hardly be overdone on roadways. Any excavation that extends into a road, and particularly into a high speed highway, is just asking for trouble. And it is not enough to mark it so well that only one in a thousand would fail to notice it—10,000 cars might pass while it is open. And the police, the lawyers, and the newspapers will not be interested in the 9999 who didn't crack up in it. Just in the one who did.

Insect Stings. Clearing and excavating brings men into painful contact with hornets, yellow jackets, and other stinging insects so often that it is one of the special risks of the business.

While in most cases no serious injury results, such stings can be more dangerous than is commonly realized, and they cause a number of deaths every year.

They respond excellently to proper and early treatment.

There are three dangers:

- Allergy to the injected poison, which will cause exaggerated reactions, and if very severe may result in shock or death from a single sting.
- Stings close to the eyes or other vulnerable parts, that may disable a normally sensitive person.
- Multiple stings from a swarm of insects may produce serious poisoning.

Most trouble comes from unexpected contacts. Preliminary scouting of an area on foot may reveal the location of nests, particularly of hornets on branches.

When possible, such nests should be destroyed in advance of the work. This can be done at night with little danger, as the insects are then sluggish and nearly blind. Also, as they are all nested, a 100% kill may be effected.

Ground nests are eliminated by pouring ¼ or ½ cup of any DDT spray down the hole, then tamping dirt in the top.

Paper hornet nests should be wrapped in wire screening, mosquito netting, or cloth, cut off the branch, and burned on a hot fire or kept under water for at least 48 hours.

The man doing this job can be protected by heavy clothing, gauntlet leather gloves, a hat or helmet, and a head-protecting mosquito net. The last item is the most important, as face stings are painful and dangerous.

If it is necessary to work among ground nests that have not been treated, they should be completely destroyed by pushing out or deep burial on the first approach. The insects are then disorganized and less likely to attack, particularly if the machine is kept in motion.

Minimum protection for operators in a danger area is a head net.

A man known to be particularly sensitive to stings should be kept on safer work until he can be desensitized to the poison by a series of shots.

Treatment. Treatment consists of stopping the swelling, slowing absorption of poison into the system, and stimulation to help to overcome its effects.

Three minims (a minim is 1/15 of a cubic centimeter) of adrenaline, divided among two or more shallow injections at the edge of the swelling, will constrict the blood vessels, stop enlargement of the swelling, and wall off the poison. This treatment should be a routine precaution for any sting near the eyes.

A dose of the same size injected in the upper arm rallies the system for defense. If no "lift" is felt the arm injection can be repeated in ten minutes, or sooner if the patient is unconscious.

These injections are made much more effective by addition of equal amounts of Chlor-Trimeton (strong solution) or some other injectible antihistamine to the adrenaline before injection.

Ordinarily, injections can be made only by a doctor or a nurse. Automatic injectors, known as Ampins (Strong Cobb & Co., Cleveland 4, Ohio) can be obtained through physicians for lay use in emergencies. The small size, filled with ½ cc of adrenaline (other drugs are obtainable in the same units) can be used for the stimulating shot in the arm.

Nephenalin (Thos. Leeming & Co.) is a pill used chiefly as an asthma remedy, which is also very effective in sustaining a victim of stings until he can see a doctor. It is held under the tongue for five minutes, then swallowed.

It is available only on doctor's prescription, and so must be obtained in anticipation of an emergency, not after it occurs.

Stings left in the wound should be removed promptly, before swelling is severe, by pushing sideward with a needle or pin. Tweezers may squeeze more poison out of the stinger into the victim.

If the sting is on a hand, any rings or slip-over wrist watch bands must be removed at once. A dentist's drill is the ideal tool for cutting a ring after it is surrounded by the swelling.

The most vital factor in treatment is quick action. Every minute of delay increases the extent of the injury, and danger of shock. Even single stings in sensitive people, and multiple stings in anyone, should have prompt attention.

In the absence of all other remedies, shock from this or any cause can be reduced by strong black coffee, taken by mouth if the patient is conscious, rectally if he is not.

Surface applications of mud or ointments may relieve pain, but have little or no effect on swelling or systemic reactions. Use of such remedies should not be discouraged, however, as they satisfy the man's desire to "do something."

INSURANCE

Every contractor needs insurance.

The only questions are what kinds and how much.

There are two types of insurance. One protects property owned by the insured, so he is paid if it is damaged or lost. The other protects him against claims for damage to other people because of his negligence. They are both important, but the second much more so than the first.

Much of the insurance protection a contractor needs is required by the majority of business men, but there are special angles.

To the layman, insurance policies are complicated and confusing. There are many kinds of coverage, some of them overlapping; and many circumstances that affect each type. It is important to go to a good broker or agent who can explain in detail the purpose of each policy and what it covers, and even more important, what it does not cover.

Self-protection. To protect his own property, a contractor should have fire insurance on his buildings and their contents, and separate all risk "floater" insurance on his equipment. Cars and trucks may be covered under the floater, or under separate motor vehicle policies for fire, theft, collision, and other damages.

The building insurance is made more complete by extended coverage, added at moderate additional cost, that protects against damage from wind, storm, hail, aircraft, vehicles, smoke, and certain other causes. Vandalism, earthquake, and some other coverages may need special endorsements on the policy. It should be remembered that these, and flood damage, are not included in extended coverage.

A good tools and equipment floater policy will protect a contractor against most damages to the machines—fire, theft, overturning, tornado, upset, and collapse of bridges. But riot, vandalism, malicious mischief, and "loss while waterborne" are probably included only if an extra premium is paid.

Such a policy may list all pieces of equipment covered, or list the large units and lump the smaller ones. Another method is to declare a gross value for all the machinery, and pay a premium on that. If equipment is listed individually, there is usually automatic coverage of new machines for a short period after purchase.

Compensation. Workmen's compensation insurance, required of employers by law in practically all states, and by common sense and self interest in all of them, pays medical expenses, part wages (as disability benefits) and damages to employees injured on the job. Usually there is a period of time, such as a week, in which compensation pays no wages unless the disability extends over a longer period. There may also be gradations from partial to full compensation for time lost, as the no-work period lengthens.

Premiums are based on the type of work and the amount of the payroll. Rates and requirements differ in various states, and a contractor working across state lines must take care to see that he is covered on both sides.

Liability and Property Damage. Liability insurance pays for injuries to people caused by acts of negligence for which the insured is liable. Property damage pays for similar injury to property.

A contractor is neither a business man nor a good citizen if he does not keep himself well insured for injuries and damage to others. His equipment and the nature of his work both make it likely that claims will be brought against him. He cannot afford to be put in bankruptcy by an operator's carelessness, nor should he risk causing damages for which he could not settle.

All too many contractors, and other business men also, think they are completely insured until an accident shows a

hole in their coverage. This section will point out a few of the pitfalls, but the best precaution is to be friendly with a good insurance man, and talk to him freely about jobs and work methods.

Most liability policies have a minimum coverage of $5000 for injury to one person, and $10,000 for injury to two or more in the same accident. The policy covers each of a series of accidents in the same amounts, until it expires or is cancelled. Property damage minimum may be $1000.

In this time of fantastically high awards of damages, these minimum coverages are much too low. Amounts can be increased for a comparatively small cost, and it is usually sound policy to carry $100,000 to 300,000 liability, and 25,000 property damage.

In addition to the face amount of insurance, the company pays for investigation and for legal and trial costs, bonding fees, and release of attachments, which may add up to substantial costs.

Exact coverages of policies vary from company to company and state to state, so the following discussion is only a general guide to what might be included.

First there is motor vehicle insurance, on personal and business cars, pickups, trucks, trailers, and on equipment that travels under its own power or is towed on public roads. This includes wheel tractors, graders, and self-powered scrapers.

Rates on trucks increase with their gross weight. At this writing, rates on wheel tractors and other heavy, slow moving equipment are prohibitively high. Arrangements can sometimes be made for coverage on job-to-job moves under the general contractors' liability. Careful investigation should be made of this point.

Towing a trailer of any kind may invalidate car or truck insurance, unless provided for in the policy, or the trailer is separately insured. If such towing of an uninsured trailer is rarely done, the company insuring the vehicle should be willing to issue a special endorsement or binder to cover the combination for a specific trip or time period, at little or no cost.

If there are a number of motor vehicles, economies may be affected by insuring them together in a fleet policy, and by keeping some of them on low mileage and therefore low rate local errands.

Contractors' Liability. There are a number of classifications of liability risks for the contractor that can be insured separately. It is good business to lump as many as possible in a comprehensive policy, to avoid extra payments on overlapping coverage, and to avoid confusion.

A comprehensive policy may cover the following:

Ownership, use and operation of buildings and premises
Elevators
Completed work (Products) having defects causing injury or damage
Teams
All contractual work of kinds specified in the policy
Operations of subcontractors, except in maintenance of the property of the insured.

It probably will not cover:

Dogs, animals, boats, aircraft, or vehicles
Blasting
Damage to subsurface pipes, conduits, and wires
Collapse of structures caused by excavation or underpinning work
Tunneling and bridge construction
Obligations assumed for others
Damage to rented or controlled equipment

The first exclusion in the above list is made because these risks should be covered by other types of policy. The next four are high-rate risks, and losses incurred under them can be more justly paid by

those who do such work, than by the larger number of contractors who do not.

These risks can be covered for specific jobs, usually only after inspection by the company so that it can see what it is letting itself in for, and set the premium accordingly. It is to the contractor's interest to have such inspections made to obtain the necessary coverage; not only for his own protection, but because it is only the most experienced of supervisors who will not benefit from talking over a job with a good inspector.

Employers often feel that inspectors are a threat and a nuisance, but they perform invaluable services both as safety engineers and job consultants. Contractors who will listen to their discussions of methods used on other jobs will often find that they will save more than the cost of the premiums charged and the safety procedures required.

"Obligations assumed for others" is a tricky one that has caused many painful surprises. It is a too-common practice for an owner to write up a work contract specifying that the contractor assumes all liability for everything that happens on the premises while he is working on them. This may extend the contractor's risks far beyond the premium he pays for his own activities. It is much better for the owner to take out an owner's risk policy for work in progress, and ideal if he can place it in the same company that insures the contractor.

If this is not possible, the contractor can show his contract to his own company, and pay an extra premium for an endorsement to cover any obligations he has assumed under it.

If such precautions are not taken, the results of the owner passing his responsibilities to the contractor may be disastrous to them both, as neither of them are insured for the owner's risks, and both are responsible for them.

"Damage to rented or controlled equipment" is another joker on which many a contractor has tumbled, although the amounts involved are usually modest. Liability policies are designed to protect against claims for others. If a contractor hires a machine, it is his for the period of use, and is no longer entitled to be the subject of a claim against him.

Coverage to protect such equipment can be obtained by endorsement of the liability policy. The extra premium is usually based on the rental cost.

Rates. Insurance is priced so that each class of risk will bring in enough money in premiums to pay sales, administrative, and legal costs, the claims that have to be paid, and to leave a surplus for reserves, and dividends to stockholders or policy holders.

An increase in losses automatically results in an increase in rates, although this effect may be delayed. The increase may be applied generally to all those having the particular type of insurance, or specifically to those whose accidents have piled up the claims.

Most insurance is written on one or more basic rates covering a general class of risk, with upward or downward revision depending on local conditions, and experience with a particular risk or a particular customer.

Fire insurance premiums are affected by how likely the property is to take fire, how readily and completely it will burn, and the availability of fire fighting equipment and water. A substantial drop in rates can sometimes be obtained by building alterations, digging a pond or providing access to it, or having a branch fire station established in the area.

Premiums are usually quoted on a basis of price of $1000 of coverage.

Contractors' liability and property damage rates are extremely variable. They are based first on experience with a particular type of work, so that blasting will have a higher rate than landscaping. Again, cover-

age for blasting in the country may be at nominal cost, where in a city it might be as high as 50% of the payroll.

A small contractor may be just carried at the average of the industry. A larger operator will be assigned an experience rating, based on the number of accidents he has had, and how expensive they have been. This rating may make his insurance more or less expensive than that of his competitors, and may thus affect his position in competitive bidding.

If the record is extremely bad, the rate may go so high as to make it difficult or impossible to stay in business. Companies might also refuse to write any insurance for him.

The premium for compensation insurance basically consists of a percentage of the payroll expressed in terms of dollars per $100 of wages. At the start of the policy term, the company and the insured define the risks that are to be covered, estimate the payroll for six months, and set the premium on the basis of the estimate. Then every six months the company makes an inspection of the insured's books, or perhaps only of his payroll tax returns, and an additional amount is charged or a credit issued for any difference from the estimated charge.

If a contractor has a number of different activities, and does not keep separate payroll records for them, he will be charged the rate of the most expensive coverage for all of them. It is therefore to his interest to keep the different classifications at least roughly divided.

Liability insurance may be assessed according to the payroll, or by the value of the work done during the period. Here also a separation should be made between jobs carrying different rates.

The contractor must pay liability premiums on all work done for him by subcontractors and by hired machinery unless he obtains and shows to his company certificates of insurance coverage from the subcontractors.

BONDS

The excavating contractor shares with other forms of business the danger of serious loss through dishonesty of an employee, or employees. For a contractor, the loss is as likely to be in property taken or sold "over the fence" as it is money.

Fidelity bonds of various types are available for protection against losses of this nature.

Construction contract bonds are required of contractors performing work for Federal, state, and local governments. There is an increasing use of them in contracts with private owners.

A bond is a three party agreement, made by the contractor and the bonding or surety company to protect the owner. It usually covers all obligations that the contractor assumes on the job, including completing the work to specification, and paying subcontractors and employees so that no liens or actions can be brought by them against the owner.

Three types of bonds may be involved. The first, the bid bond, accompanies a bid or proposal on a job, and guarantees that if the bidder is given the job, he will enter into a formal contract to complete it, and will supply bonds to complete the contract.

The bond supplied for the work itself is made up of two bonds, which are separate, but seldom if ever written separately. One is a Performance Bond, covering fulfillment of the contract, the other a Labor and Material Payment Bond, guaranteeing payment to personnel, suppliers, and subcontractors.

These last two are drawn separately so that no question of priority can arise when claims are presented by both the owner and those who have supplied services and materials. In the early days of bonding, the

government had to be paid or satisfied first, and the others got what was left. This meant at least long delays, and in cases where the bond was too small, losses for the small claimants.

In order to obtain a bond, a contractor must convince the company that he is competent to do the job, and financially able to carry it. He pays the premium, usually not over 1% of the contract price, figures it as part of his cost, and passes it on to the owner in his bid or estimate.

Substantial all-around benefits are sometimes obtained from writing of construction bonds. The owner can let the contract to the lowest bidder without having to inquire into the question of whether he can complete it, as the bonding company guarantees performance. The contractor may save money by driving hard bargains with subcontractors who cut their figures a little closer because they know they will be paid.

If a contractor fails to complete the job or to pay the subcontractors, the bonding company takes over, lets a new contract to finish, and pays up the bills. Quite often, the new contract will be let to the contractor who defaulted, as his equipment is on the job.

The contractor is legally obligated to repay to the surety company everything that it has spent to finish his work. The company makes a more cooperative and intelligent creditor than a combination of an enraged owner and starving subcontractors, and in most cases the contractor is able to work his way out of his difficulties, and avoid a failure that might have been inevitable without the protection of the bond.

Unfortunately, there is another side to the picture. Many contractors who are thoroughly competent and reliable and have adequate resources for a job cannot get a bond to cover it. Potential low bidders may thus be weeded out, and work concentrated in the hands of a favored clique.

Inability to get a bond may result from a poor background, lack of resources, too many jobs already in progress, or other reasonable causes. All too often, however, it is the result of cloudy judgment or caprice.

Bonding companies usually know very little about construction work or the ability of men to do it. Yet they are acquiring the power to decide which contractors can work and which must starve, and to meddle with work and accounting methods. They work together so closely that a contractor rejected by one of them has very little chance of obtaining coverage from another.

Requirement of a bond in private work is therefore often productive of injustice and hardship and may result in substantially higher costs. The owner can usually obtain adequate protection by exercising good judgment in awarding the contract, and by the customary withholding of a percentage until the job is finished.

CHAPTER TWELVE

HINTS ON MAINTENANCE

LUBRICANTS

A fundamental necessity for machine operation is proper lubrication. The lubricant provides a slippery film between surfaces rubbing, turning, or scraping on each other. This film greatly reduces friction and the wasted power, wear, and heating that friction causes. Lubricant may also serve as a cooling medium and as a barrier or cleaner to keep abrasive material from getting or remaining between moving parts.

Oil and Grease. Lubricants are called oils or greases. Oils are fluid and vary from the extreme thinness of penetrating oil to the slow flowing transmission oils, which are more often called greases. The term grease may be said to include these thick oils, but more specifically means the semi-solid and solid mixtures of oil with special soaps or fillers which give the combination the qualities of body (flow resistance), adhesiveness, pressure endurance, water resistance, and melting point on the basis of which greases are selected.

Dip Lubrication. Transmissions and other gear boxes usually are partly filled with oil or fluid grease. Some of the gears are partly immersed in this lubricant and carry it on their teeth to the higher gears with which they are meshed. Other gears, bearings, and splines are lubricated by splash, by gravity flow of oil carried higher points, or both.

The dip method is best suited to heavy lubricants which cling to parts enough so that adequate quantities will be picked up and transferred to higher levels. Rotation should be slow and construction simple enough so that local hot spots will not result from uneven distribution of the lubricant.

When engines are lubricated in this manner the crankshaft usually has projections which dip into the oil and splash it around so that it reaches all surfaces requiring it.

An engine or a gear box may be lubricated partly by dip and splash, and partly by pumped oil.

Many gear boxes have shaft seals made with Neoprene or other special materials, which may be attacked by chemicals found in some oils. The manufacturers will supply a list of safe oils that do not contain these chemicals, and use of any other brand may prove very costly.

Pump Systems. A pump may pick up oil from a reservoir, usually the crankcase or oil pan under the engine, and force it through the crankshaft and camshaft in drilled passages which have openings in each bearing. The amount of oil which escapes at each point is regulated partly by the size of the outlet, but chiefly by the closeness of bearing fit. Connecting rods

may also be drilled to carry oil to wrist pins. Parts not reached directly by pumped oil, such as cylinder walls, are lubricated by an oil mist generated by leakage out of the bearings, and by dipping and splashing as well. All oil returns to the reservoir to be picked up again by the pump.

A weakness of many of these systems is that the pump moves only sufficient volume for normal requirements. If bearings wear or the oil becomes too thin, through error in selection or because of dilution or too much heat, an excessive amount of oil will escape at the bearings. This will lower the oil pressure and make it likely that the last bearings in the series will receive too little lubricant, with resultant damage. When the engine is idling, pressure may also be inadequate to reach all bearings. Another disadvantage of low oil pressure is that it may materially reduce the volume and effectiveness of the oil mist.

These weaknesses should be avoided by using an oversize oil pump with a capacity in excess of any probable need. A pressure relief valve that will spill the excess back into the crankcase can then keep the oil pressure at a constant level in spite of thin lubricant, low speed, or loose bearings.

Oil should be checked every morning before starting the engine, and more frequently if it is found to be necessary. The operator should keep an eye on the oil pressure gauge, particularly when operating the machine at steep angles that might interfere with normal pump action.

Diesel Lube Oil. Diesel engines tend to produce sludge and varnish-depositing compounds as by-products of combustion. Special heavy duty oils have been developed that contain detergents that keep these substances in suspension, rather than making harmful deposits. It is absolutely necessary that these be used instead of ordinary motor oil.

Such oils can also be used to advantage in gasoline engines. On the first filling they may pick up so much accumulated sludge and varnish as to need to be changed very quickly, but this cleanout is very beneficial to the engine.

Some of the heavy duty motor oils sold at premium prices are suitable for use in diesels, but the engine manufacturer should always be consulted before trying any brand.

Detergent oils are usually recommended for wet clutches with metal plates or plate lining, as varnish deposits interfere with their performance.

Dirty Oil. It is difficult or impossible to keep foreign materials out of oil. Dirt can enter an engine through outside contamination of oil in cans or funnels, by the oil dip stick that often is so located that it is very difficult to avoid touching it to dirty parts when checking oil level, through an inadequately protected or improperly serviced air intake and then past the piston rings, or through an improperly protected crankcase breather. (When an engine pulls, it tends to build up pressure in the crankcase, when it decelerates or holds back a load by compression a vacuum may develop which will suck air in. These effects are very slight in a new engine and increase with wear of piston rings and cylinders.) Carbon may work down from the combustion chamber and metal particles may appear from anywhere. A machine whose engine pan gets in the dirt, such as a tractor, may take in some of it through holes in the oil pan or past a defective seal on the rear main bearing.

Pump systems may be protected by filters. There is usually a screen at the pump intake, but this is a comparatively coarse mesh which is useless against the finer particles that cause most of the extra wear. Of more importance are the line filters which contain replaceable elements of fiber, cloth, or paper, or permanent ones of closely spaced metal discs or porous stone.

The difficulty with most filter systems

is that the filter is located in the return line from the shafts to the reservoir. Also, they are frequently so hooked in that they will filter only part of the oil flow.

As we have seen, all serious sources of dirt in engine oil put it in the crankcase first. A particle may be put through the system several times before it happens to get in the filter. If it escapes through a bearing it may re-circulate dozens of times, each time taking a little metal out of the bearing, the shaft which rides in it, or both. Small particles, fine sand size and smaller, are likely to stay active much longer than coarse ones. If highly abrasive, like sharp silica particles, a fraction of a teaspoonful may cut a big engine to pieces before it is filtered out. More damage may be done in a few hours or even minutes than in years of normal operation.

The logical answer to this danger is to place the filter between the pump and the engine, and to make it of sufficient size to filter all the oil going into the engine passages. The pressure gauge, if tapped into the line after the filter, will give warning of any clogging sufficient to reduce oil flow.

Dirt may get in a gear box through defective seals on shafts, from cans or funnels, from dirt dropped in while removing filler plugs, metal grindings, and suction caused by temperature changes. Thick oil and leisurely turning of the parts allow most of this material to settle down into a sump that should be provided just above the drain plug, where it will be largely drained out while changing oil. Some particles, however, will remain in circulation, damaging parts with every passage through them.

Since oil is changed in these units at long intervals, and breather plugs, if any, are small and easily serviced, the most serious contamination comes from metal filings. These are produced very slowly if the unit is in good condition, and more rapidly as bearings wear and shafts and gears get out of line. A large quantity can be permanently taken out of circulation by using magnetic drain and check-level plugs, which will hold them until removed for cleaning.

The only cure for dirt in a dip or splash system is to change the oil. This should be done when the unit has just been operating long and fast enough to warm the oil and pick up the dirt. It is a good plan to follow draining by putting in a thinner oil, running long enough to give it a chance to wash all parts, then draining that.

Grease. Pressure fittings must be greased at least as often as recommended by the manufacturer. Under unfavorable conditions, as when seals are defective, wear has created abnormally wide clearances, or there is unusual exposure to dirt or water, greasing should be more frequent.

Hinges which must work in the dirt, such as track pins and bushings, last longer if run dry than if lubricated.

In general, better lubrication is afforded by a little grease often than by a lot now and then. It is more effective at preventing the bearing or joint from running dry at any time, and at preventing entrance of dirt.

After dirt has worked into a solid bearing (bushing) it can often be pushed out by heavy greasing. Cleaning is most complete if the unit can be rotated while grease is forced in. Even if it is not possible to get all the dirt, it is seldom desirable to disassemble it for cleaning, as the value of the parts and the amount of damage from the dirt is not likely to justify the labor cost and lost time.

If there is no seal, and both the shaft and the bushing are hard steel, plugged passages can be opened and dirt and old grease forced out by removing the fitting and exploding a blasting cap deep in the grease passage.

Ball and roller bearings are very vulnerable to damage by dirt. They are usually protected by seals. If dirt gets in one the

machine should be stopped and the bearing taken out and cleaned, as otherwise it will be destroyed very quickly.

The type and quality of grease is important. Slow moving solid bearings or bushings operating under light load will function well with almost any grease, but best results and longest intervals between greasings are obtained by using a type thick and sticky enough to stay where it is needed. High speeds require heat and pressure resistance to enable a thin film of lubricant to persist at spots or lines of extreme pressure, to avoid channeling or gouging it away from the places where it is most needed. The wiping action of worm and hypoid gears will clean ordinary lubricants off the tooth surfaces.

If the location is hot, a grease which does not soften and run out at high temperatures is required. If there is exposure to water, water resistant grease having the other necessary qualities should be used.

Incidentally, the thick waxy grease used in older type water pumps is a service man's best friend for keeping bolts and nuts free of corrosion. It keeps threads oily and easy to turn for long periods if put on the threads before connecting, and smeared on the outside afterward.

If greasing is done too generously or too often, so that more lubricant is supplied to a bearing than it can use, damage of various types may be caused. If the seals are of a type that will not permit the passage of grease, the tremendous pressure built up by either hand or air guns may destroy the seal, or deform or burst the casing.

If the grease escapes readily it will build up around the casing, and if in large quantities, will run down onto other parts of the machinery or to the ground. It will combine with dirt and trash to make a nasty mess, and may ruin clutch and brake linings.

One "all purpose" lubricant can be used for a variety of applications, but seldom provides as good lubrication as specialized greases. However, the simplification of lubrication they make possible often means more regular and conscientious greasing, so that the net result is much better.

Hand Guns. The majority of hand grease guns now in production are the lever type. Figure 12-1 shows a typical example in cross-section. The cylindrical barrel has a smooth inside finish. The metal piston with leather seals is pushed toward the head by a light spring. The follower rod is used to pull the piston back against the spring when refilling by suction. The collar groove in the rod permits locking it in the back position.

The head contains a fitting through which grease can be pumped into the reservoir, and a passageway from the reservoir into the nozzle tube. A piston actuated by the hand lever moves up and down in this passage in which a ball check is located.

When the piston is pulled up, grease or air in the tube is prevented from following it by the check. This leaves a vacuum so that when the passage to the reservoir is opened, grease is sucked into the passage. The grease is urged in by the pressure of the follower spring, and by atmospheric air entering the barrel around the follower rod in the back cap.

When the piston is moved down it blocks the reservoir passage, then forces the grease down and compresses the check spring so that the grease can flow past the ball into the tube. When the piston is raised, the ball reseats itself and the passage refills from the reservoir.

The small piston and the comparatively long lever enable this gun to develop pressure up to 10,000 pounds per square inch. Most nozzles and fittings are designed to take 20,000 pounds pressure. However, the seals and casings of the parts being lubricated will often bend or break at less pres-

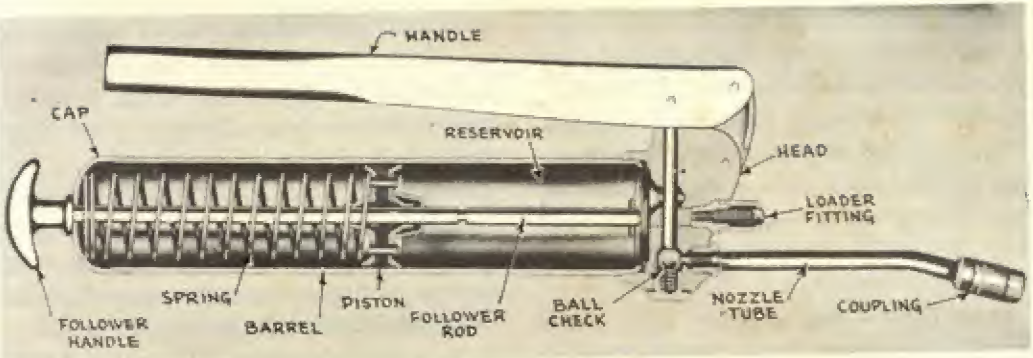


Fig. 12-1. Lever-type hand gun

sure so caution must be used when forcing grease into them.

The gun may be filled in three ways. The easiest is to pump grease into it through the fitting in the head casing from a loader pump. Precautions should be taken against pumping in air with the grease.

If there is no loader fitting, or no loader pump is available, the head casting is unscrewed, the head of the barrel cleaned and pushed well down in the grease supply, and the follower arm drawn back slowly. If the grease is thin enough to flow, it will be sucked into the barrel. It may be necessary to move the gun around in the container to prevent air from entering. When the follower is fully back it is locked with a sideward motion, the head screwed on, and the follower released. It is good practice to keep the grease in a warm place to keep it soft enough to flow.

If the grease cannot be pumped or sucked into the gun, it may be put in with a small paddle and air kneaded out of it. It is difficult to avoid air pockets with this method.

Air in the grease may form a pocket in the passageways that will prevent the gun from working. The block may be temporary until the air is worked out, or permanent if the gun is worn enough to allow it to return beside the piston into the reservoir.

Air takes much longer to get through the head than the same bulk of grease. However, many times a gun is said to be air locked when the trouble is partly or wholly foreign matter which prevents the ball check from seating properly. This allows grease or air to be sucked into the cylinder from the outlet tube on the up stroke, and pushed back into it on the down stroke.

In either case the cure is to disassemble the unit, clean it, and pack it with fresh grease.

The outlet tube consists of a piece of ⅛" pipe, or of equivalent size flexible hose. Pipe thread is used. Any of the standard couplings can be attached to this.

Thick grease may not feed properly in this type of gun, as combined atmospheric and spring pressure may not be enough to make it flow. It may be persuaded to work by tapping or by heating. Best results may be obtained if the follower piston is so built that the rod can be locked to it (as in this example) so that pressure can be applied while pumping.

A special gun may be obtained in which the grease is forced along the gun by twisting a threaded follower.

A small dab of grease is usually left on the Zerk or hydraulic fitting as the gun is pulled off. This should not be wiped off until the fitting is to be greased again, as it protects the grease passage against dirt that would otherwise lodge in it.

Button head fittings can be wiped clean, as they have no dirt-catching opening.

Asphalt-Base Lubricants. Exposed gears on revolving shovels, various other types of open gearing, and sometimes wire ropes, may be lubricated with an asphalt derivative, known under various trade names, and recognizable by their tar-like appearance.

In its natural state it is too hard at ordinary temperatures for use in any type of grease gun or dispenser. It is applied by heating, then pouring it in a thin stream on revolving gears or painting it on stationary ones with a brush.

The most convenient way to handle it is to heat the original container, usually a thirty-five pound pail, and pour it into a number of small cans. One can is kept ready for use by hanging it or resting it on the exhaust pipe or manifold.

At least one brand is supplied mixed with a volatile solvent, so that it can be applied without heating, and hardens on the gears as its carrier evaporates.

Small amounts of either type should be used often, as most of a heavy application runs or works off in a few minutes. The surplus builds up hard deposits underneath that may interfere with the gear or with other machinery below. Such accumulations are very difficult to remove, particularly when combined with dirt.

Asphalt-base lubricant cannot be removed from skin or clothing by ordinary cleansers. However, it is readily softened by lubricating oil and can then be removed by wiping or washing.

ADJUSTMENTS

Tracks. Crawler tracks, whether of the shovel or tractor type, give longest service if kept at correct tension. If too tight, the hinge pins will operate under excessive load, and wear rapidly. If too loose, there will be extra and unnecessary motion in the hinges in the upper section when going forward, and in the bottom when backing against a load. Slack may rub against and wear through final drive cases or other machine parts. Danger of jumping the track is greatly increased.

In general, a track is correctly adjusted if there is a slight sag in the top section when the machine is or has been moving forward. If there is an upper support roller, it should be possible to pry the track up from it an inch and a half to two inches. The total sag permitted in a long track is greater than in a short one. A new track may be operated with more slack than an old one that is more likely to come off.

Adjustment on a tractor is made by moving the idler forward to tighten or backward to loosen the track. All the more common arrangements involve a single large bolt threaded into a nut or socket.

Turning the bolt is excessively difficult except on new machines. Dirt works into the threads and cements the pieces together. The hexagon grip is usually difficult to get at, and the wrench that comes with the tractor is likely to be both a poor fit and poor steel. It may not allow a long enough arc of turn, so that an additional wrench with a different handle angle is required. A good quality wrench is often a sound investment anyhow.

A heavy pipe is used to extend the handle to obtain leverage.

A very few manufacturers are intelligent and considerate enough to enclose the adjustment in a case or to seal it against entrance of dirt, so that the threads can be kept clean and oiled. Tracks so equipped are almost always easy to adjust.

It is good practice to anticipate the time of track adjustment for a few days, and apply penetrating oil and perhaps some "rust-buster" liquid ahead of time. These fluids also help at the time of adjustment. Heating the nut or socket with a torch

will usually crack the dirt bond and permit turning.

Shovel tracks are usually adjustable at both ends, and each adjustment uses a pair of bolts, one on each side of the wheel. The idler is moved to adjust the track only, the bull wheel to adjust both the track and the drive chain. Nuts are usually lugged, and the special wrenches are better than those that come with tractors.

Care must be taken that both sides of a shovel wheel are adjusted equally, as if the wheel is cocked sideward, it will tend to climb out of the track.

Extreme difficulties are encountered with stuck adjustments. It is good practice to wrap all exposed threads in rags, and keep them well oiled. Sometimes packing with stiff water pump grease will keep them in usable condition.

Shovel tracks get considerable wear when the machine is standing still, as the machine tends to move back and forth on them as it digs. Keeping the chains to the rear on a dipper shovel and to the front on a hoe and a dragline minimizes this damage.

Tractor tracks take their worst beating in sharp silica sand and in deep sandy mud. High speed also increases wear out of proportion to the extra distance covered. Such damage can seldom be avoided, but it should be considered when pricing a job.

Track chain life can usually be lengthened by turning pins and bushings 180° before the bushings wear through, or by building up the worn parts of bushings with medium hard steel.

Both track rails and rollers tend to wear more on their outer than their inner edges, eventually producing a slope that encourages the track to run off at the slightest excuse. In this situation building up or replacing either the track or the rollers gives only a doubtful temporary cure. For a thorough repair tracks, rollers, and idlers must be fixed all at once.

Special machines are available that will turn a roller as it is built up by welding, to obtain a layer of uniform thickness and keep the roller round. This work is not cheap, as the insides are to be taken out first to avoid heat damage, but it is usually less expensive than replacing the roller shell.

Shovel dozers, and usually bulldozers also, are equipped with roller guards. These are plates extending from the track frame down almost to the track shoes, and serve to keep dirt and stones from sliding onto the track during turns. They should be replaced as part of a track and roller overhaul, as they give valuable protection which diminishes as they wear down.

Clutches and Brakes. In most machines, a mechanical clutch or brake should not drag when released, and should not slip when engaged. Exceptions are cushion clutches which will slip a certain distance under a shock load before re-establishing a solid connection, and safety clutches which will slip rather than transmit enough strain to break parts. These units save damage to machinery and cables from sudden increase of load or hitting obstacles.

Friction clutches on excavators and cranes are sometimes adjusted so that they will not carry the full engine power to the load, either to cushion shocks, to prevent overloading of the boom or cables, or as a safety precaution against picking up a tipping load. Except in light work, this is likely to result in excessive slippage, heating, and wear. In addition, it usually requires too-frequent adjustments, to keep on the hair line between dangerous slippage and solid engagement.

Brakes which have increased leverage as the pedal nears the bottom of its range are sometimes left loose to reduce the effort of applying. This is a dangerous prac-

tice, as heating of an external brake, or reduced friction between lining and drum from seepage of lubricant, or other causes, may cause a complete failure to hold with the pedal down to the floor, which would not have occurred if a higher pedal position permitted further movement.

Some clutches and brakes will chatter under certain circumstances, often when only partially engaged. This nuisance is usually caused by defective design, but it may be caused or aggravated by gummy linings, out-of-round drums, and wrong hook-up or looseness in the linkage. The condition should be corrected if possible, as it is fatiguing to the operator, makes delicate crane or grading work difficult or impossible, and causes or hastens crystallization and failure of shafts, cases, and clutch parts.

It often happens that a machine has clutches and brakes which work easily and smoothly when new, but which gradually degenerate so as to require excessive effort. Relining, turning down of drums, or routine overhaul may fail to restore their efficiency. In such cases, the trouble may be in some adjustment which is repeatedly made wrong. More often, it is lost motion in the linkage. A tiny looseness at each clevis and pin, inside the clutch, in its connections with the pedal or lever, and weakening of arms so that they twist may be sufficient to destroy the delicate balance which is necessary for proper functioning. Complete rebuilding or replacement of the linkage may restore efficiency, at less expense than frequent stops for adjustments, and shutdowns for relining.

A dry clutch or brake should be kept free of oil and grease. If any accidentally gets on the lining, it can usually be washed off with naphtha (this is preferred to leaded gasoline because it is less likely to leave a deposit). However, the grease may soak in so far that it will take repeated washings, alternating with sufficient use to heat it up.

After grease soaking, or from other causes, lining may acquire a hard or gummy surface which persists in spite of cleaning. Sprinkling with fullers' earth, a finely powdered clay which can be obtained in drug stores, will often restore effectiveness temporarily and repeated applications may keep the lining usable until it wears out. It is most conveniently applied with a rubber bulb syringe, another drug store item.

Pounds pressure or pull required to release a properly adjusted clutch is often specified in instruction books, but measuring this resistance is difficult in the field or the average shop. Fortunately, exact compliance with these directions is not vital. Pull can be estimated, but the important thing is that the clutch should not slip under the operating conditions prevailing. If it does slip, it should be adjusted immediately, deadlined, or at least demoted to lighter or slower duty until adjustment is possible.

If there is no further adjustment in either the clutch or linkage, lining or plate(s), the clutch friction parts should be replaced immediately, as unnecessary and expensive damage may otherwise be done to pressure plates and other parts.

A test for slippage is made by slow engagement of the clutch under heavy load in high gear.

Backlash. Backlash (play in a drive line) in splines, a jaw clutch, between the teeth of meshing gears, or between a sprocket and a roller chain, can be both annoying and destructive. If in a shaft it can be eliminated by repairing or replacing worn universals, tightening flange bolts, and building up or replacing jaw clutch teeth. Gears can be moved into closer adjustment, or replaced. If large and crude, teeth may be built up. In sprocket chain combinations, the chain frequently needs

replacement, but it is good practice to repair or replace the sprocket at the same time, to avoid too-rapid wear on the new chain.

Such work will increase efficiency, and cut down breakage costs.

Reinforcement. Excessive twist of frame members in service causes crystallization and fatigue in the metal that may result in early breakage. The amount of stress in a heavy piece of steel can be determined exactly by a $50,000 machine, or almost as satisfactorily by smearing it with mud, subjecting it to load when it is half dry, and watching the cracks.

Experience with a particular model or type of machine often indicates the need of reinforcement before placing it in service. The average bucket lip or tooth has a much longer life if it is weld-surfaced with a hard rod before it is used, and if the surfacing is renewed before wear gets into the softer metal beneath.

Dump truck frames are often reinforced by fishplating. The point of greatest stress is between the body and the cab. The usual flat reinforcing fishplate may not be satisfactory because it reinforces against vertical stresses only, and twist is an important factor in failure of frame members. Use of angles or channels produces better results. A channel inserted and welded in the frame channel is the preferred method. Fishplating should extend along at least two feet of frame, preferably three or more, and should be securely welded top and bottom. Bolting or riveting weakens both the frame and the plate.

The rear cross member may require strengthening also. Any type of fishplating, or welding a heavy pipe between the frame members immediately ahead of it, should give sufficient support.

Reinforcement is most easily installed before the body is mounted, and most effective before the frame has been strained by carrying heavy loads.

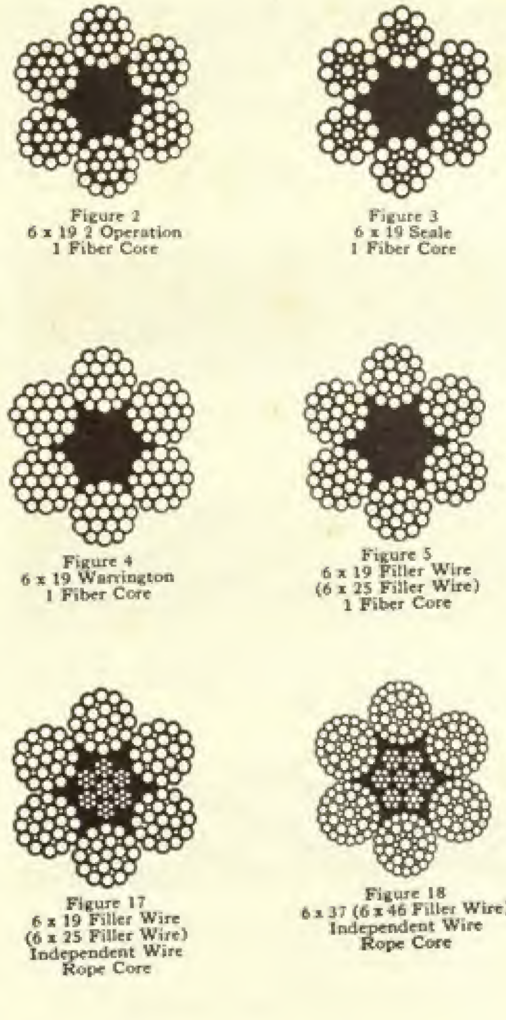


Figure 2
6 x 19 2 Operation
1 Fiber Core

Figure 3
6 x 19 Seale
1 Fiber Core

Figure 4
6 x 19 Warrington
1 Fiber Core

Figure 5
6 x 19 Filler Wire
(6 x 25 Filler Wire)
1 Fiber Core

Figure 17
6 x 19 Filler Wire
(6 x 25 Filler Wire)
Independent Wire
Rope Core

Figure 18
6 x 37 (6 x 46 Filler Wire)
Independent Wire
Rope Core

Fig. 12-2. Wire rope cross sections

CABLE (WIRE ROPE)

Cable, or wire rope, is one of the most important materials or parts used in excavation machinery. There are many types for different uses, but most of them are made up of carbon steel wires wound into strands, and strands wound with each other to make cable. The strands are wound around a center or core, which may be an additional strand, a miniature cable, or a rope made of sisal or manila. The wire core is stronger and more resistant to crushing,

REGULAR LAY ROPE

A regular lay rope is one in which the direction of lay of the strands in the rope is opposite to the direction of lay of the wires in the strands.

LANG LAY ROPE

A lang lay rope is one in which the direction of lay of the strands in the rope is the same as the direction of lay of the wires in the strands.

RIGHT LAY ROPE

A right lay rope is one in which the path of the strands in the rope is from left to right in a direction away from the observer. A right lay rope may either be regular lay or lang lay.

LEFT LAY ROPE

A left lay rope is one in which the path of the strands in the rope is from right to left in a direction away from the observer. A left lay rope may be either regular lay or lang lay.

Fig. 12-3. Wire rope lays

but is less flexible and resilient than the hemp.

A cable is designated by its size, by the grade of steel wire used in it, as to whether it is preformed, by its lay, the number of strands not including the core, and the number of wires in each strand.

A widely used construction is the 6 x 19 that is, six strands of nineteen wires each. The wires may be all of one size, or of two or more sizes. Additional wires, to a total of 25 per strand, may be added without changing the 6 x 19 designation. See Figure 12-2. . Each construction has a name, often the name of the designer of the particular

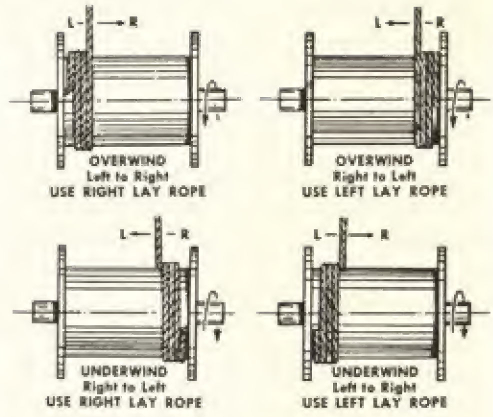


Fig. 12-4. Winding on drum

type. Variations in flexibility and in resistance to crushing and to abrasion are obtained. Small wires are desirable when the cable is subjected to sharp bending; large outer wires when it may be rubbed and chafed.

Lay. The lay of a wire rope is the direction of twist of the wires in the strands and the strands in the cable. Four standard lays are illustrated in Figure 12-3. The right and left designations indicate the direction the strand takes in crossing the top of the cable as it winds away from the observer. In regular lay the wires in the strands are twisted in the opposite direction from the strands in the cable. In Lang lay the wires and the strands both have the same twist. In practice, the difference is that the Lang lay has better fatigue resistance because of the flatter exposure of the wire, but it has a tendency to untwist unless both ends are held.

Under conditions where coarser outer wires are needed to obtain resistance to abrasion, Lang lay may be used in order to regain some of the bending fatigue resistance lost by using the thicker wire.

In the field, this is commonly interpreted to mean that Lang lay has inherently better abrasion resistance than regular lay, but when the same size outer wires are used,

the difference is negligible except under certain special conditions.

Right lay is the usual construction and is recommended for overwinding on a drum when the anchor is on the left, and for underwinding when the anchor is on the right. Left lay is preferable for overwinding from the right, or underwinding from the left. This is because the cable, when relieved from strain, tends to twist slightly as if to unwind its strands, and if used as advised above, this twisting will cause the wraps on the drum to hug each other, instead of loosening and spreading apart.

To determine whether a drum is overwinding or underwinding stand behind it, looking along the outgoing cable. If it takes off from the top or near side of the drum, it is over; if the bottom or far side, under. See Figure 12-4.

Grades. Several grades of steel are used in wire rope. The two most suited for excavation machinery are plow steel and improved plow steel. The improved variety is about 15 percent stronger than the plow steel, which in turn is considerably stronger than the mild plow and traction steels used in elevator cable, stationary guy ropes, and highway guards.

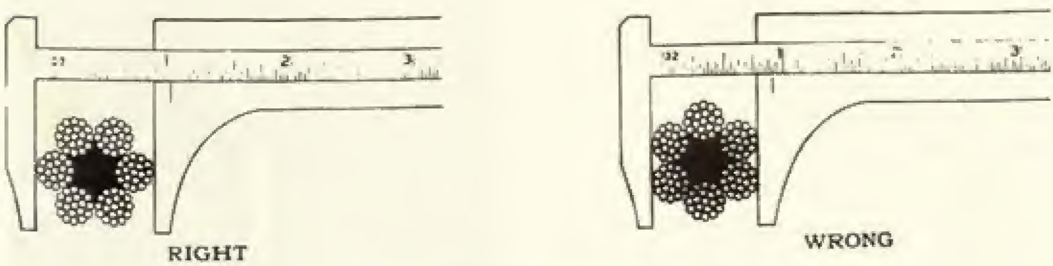
The table in Figure 12-5. gives the strength and weight of various sizes of wire rope. Size is measured as in Figure 12-6.

Wire. Cable wire is stiff and springy. In

Rope Diameter Inches	Approximate Weight lbs./ft.	Actual Rope Strength: Improved Plow Steel, Tons of 2000 lbs.	Actual Rope Strength: Plow Steel, Tons of 2000 lbs.
1/4	0.10	2.74	2.39
5/16	.16	4.26	3.71
3/8	.23	6.10	5.31
7/16	.31	8.27	7.19
1/2	.40	10.7	9.35
9/16	.51	13.5	11.8
5/8	.63	16.7	14.5
3/4	.90	23.8	20.7
7/8	1.23	32.2	28.0
1	1.60	41.8	36.4
1 1/8	2.03	52.6	45.7
1 1/4	2.50	64.6	56.2
1 3/8	3.03	77.7	67.5
1 1/2	3.60	92.0	80.0
1 5/8	4.23	107.0	93.4
1 3/4	4.90	124.	108.
1 7/8	5.63	141.	123.
2	6.40	160.	139.
2 1/8	7.23	179.	156.
2 1/4	8.10	200.	174.
2 1/2	10.00	244.	212.
2 3/4	12.10	292.	254.

NOTE:
For breaking strength of galvanized ropes, deduct 10% from strengths shown. For Wire Strand Cores and Independent Wire Rope Cores add 7 1/2% to the listed strengths and 10% to the weights.

Fig. 12-5. Strength and weight table, 6x19 fiber core wire rope



Wire Rope is usually manufactured slightly larger than the nominal diameter. The diameter of a new rope may exceed the nominal diameter by the amounts as shown in the United States Federal Specification for Wire Rope.

Fig. 12-6. Measuring wire rope

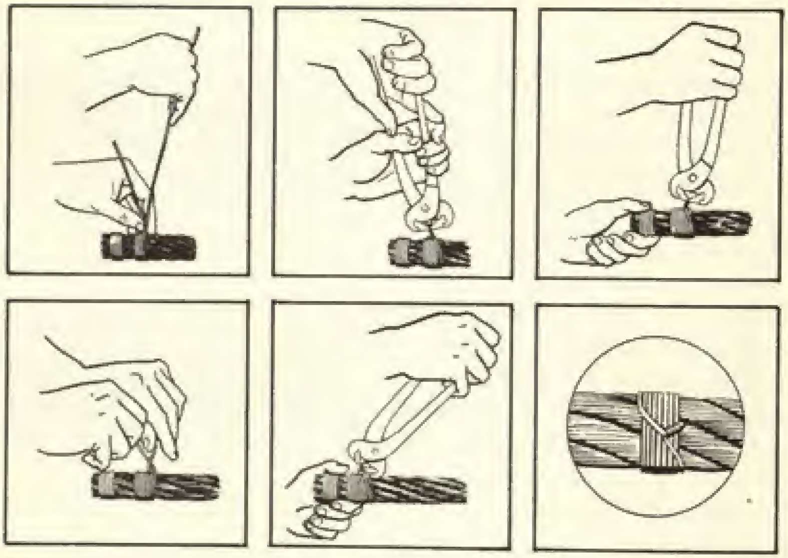


Fig. 12-7. Seizing wire rope

ordinary non-preformed construction, if a wire is cut or broken the ends will straighten and project from the rope surface at an angle. These ends cause extra wear to sheaves, drums, and other wraps of cable, and will cut unprotected hands.

If such a cable is cut or broken, the wires and strands will untwist for several feet or yards on each side, unless bound (seized) or clamped.

Preforming. Preformed cable is made of wires which are shaped so that they lie naturally in their positions in the strand and the rope. They show little tendency to stand out from the surface or to unravel when cut.

Preformed cable is safer to handle than the straight wire type and is more resistant to fatigue caused by working over small sheaves, or around sharp angles. It is recommended for use in most excavating machines, and is replacing the older type.

Seizing. Wire rope is manufactured in long pieces that are cut into shipping or working lengths by the manufacturer, dealer, or user.

Cable formed from straight wire should be firmly bound (seized) with soft iron wire in two to four places on each side, before cutting. This process is illustrated in Figure 12-7. A tighter wrap can be obtained by holding the loose end of the wire under some tension and twisting it onto the rope with bar, as in 12-8.

Large cables require more and tighter seizing than small ones.

Seizing wire should be thin enough so that the cable end will go through a socket or clamp easily. If difficulty is experienced, the cable and binding can be flattened with a heavy hammer.

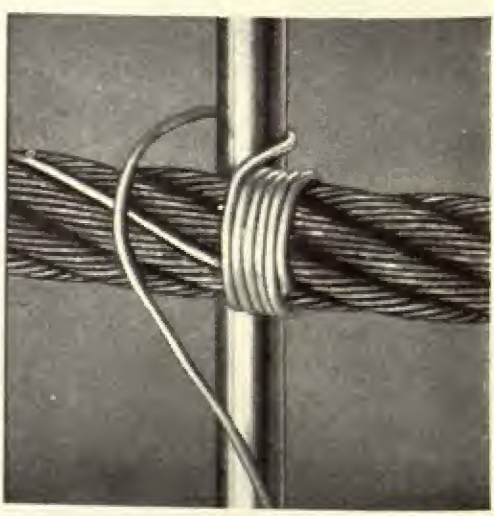


Fig. 12-8. Tight-wrapping seizing wire

Preformed cable is usually bound only when it is to be placed in a poured socket, or is to be stored or roughly handled before use.

Cutting. The best tool for cutting is an oxy-acetylene torch, as it is quick and easy and will weld the ends, prevent raveling, and reduce strain on the seizing. Next choice is a regular cable cutter, which is a concave chisel in a vertical guide. The cable is placed in a groove under the edge and the chisel struck several times with a heavy hammer. An ordinary cold chisel may also be used.

Standard bolt cutters will be damaged by the hard wires. A hacksaw is rather tedious to use. It will work best if fitted with blades designed for use on hard steel.

Bending. Wire rope is very flexible, but repeated bending causes the metal to lose its resiliency and break, usually first in individual wires, producing a weak spot that finally breaks under strain. Sharp bends, as around small drums and sheaves, are more damaging than gradual bends around large ones. Large cables, and cables made up of coarse wires, are most damaged by bending. Reverse bends break down the wires faster than two or more bends in the same direction. The damage from bending is largely fatigue in the metal, but is increased by wear and nicks on the wires from friction between them.

Wire rope manufacturers recommend that drum or sheave diameter be 45 times the diameter of the cable to minimize bending stresses. Unfortunately, it is impractical to build excavating machines up to these standards, and ratios vary from thirty down to ten or below. This results in a generally short life for cable, and in some cases it is more economical to use a small rope which is not strong enough for shock loads, rather than the recommended size which is so damaged by bending over small sheaves that it fails quickly.

Crushing. Wire rope is damaged when

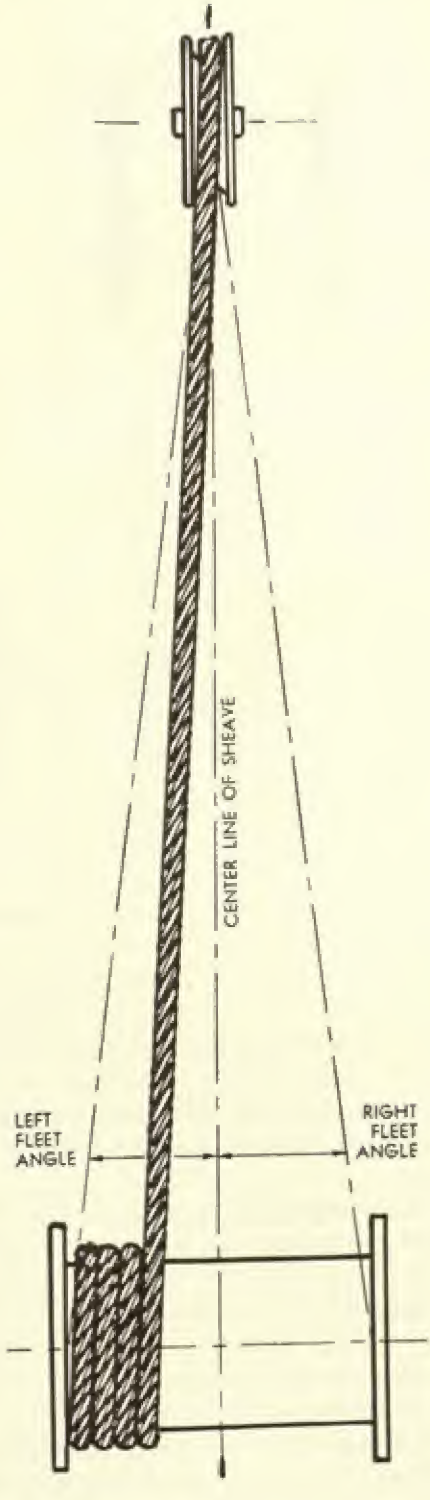
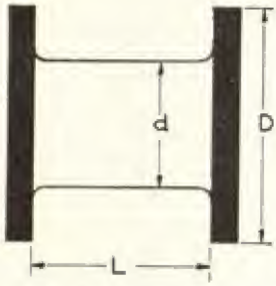


Fig. 12-9. Fleet angle



TO FIND THE WIRE ROPE CAPACITY OF A DRUM

Length of wire rope in feet that a drum will hold = $(D^2 - d^2)\ LX$

D = Diameter of flange in inches
d = Diameter of drum in inches
L = Inside width of drum in inches
X = Rope Factor—See Table below

Rope Factors

1/8 inch	4.250	1 inch	.0655
1/4 inch	1.018	1 1/8 inch	.0516
3/8 inch	.466	1 1/4 inch	.0418
7/16 inch	.341	1 3/8 inch	.0347
1/2 inch	.262	1 1/2 inch	.0292
9/16 inch	.2064	1 5/8 inch	.0248
5/8 inch	.168	1 3/4 inch	.0214
11/16 inch	.138	1 7/8 inch	.0186
3/4 inch	.116	2 inch	.0164
13/16 inch	.099	2 1/4 inch	.0129
7/8 inch	.085	2 1/2 inch	.0105

Fig. 12-10. Rope capacity of winch drum

wound unevenly on a drum and placed under strain. The wraps of cable crush and kink each other. In many machines the working end of the rope does not stay in line with the drum so that a device of pulleys or rollers, called a fairlead, must be placed between the drum and the work to line the cable up for smooth winding on the drum.

Fleet angle, Figure 12-9, is the maximum angle made by a rope with a line perpendicular with the drum. It should not be more than 1½ degrees if the drum is smooth, or 2 degrees if it is grooved. It can be reduced by increasing the distance between the drum and the guide sheave.

Kinking. Cable is severely damaged by kinking which occurs when it is pulled tight while it has a loop or twist in it. To avoid this damage it should always be unwound, not lifted, from a reel or coil. A reel should be set so that it can revolve as the cable is pulled off it. A coil should be untied, the outside end laid on the ground, and the coil rolled away, leaving the cable extended behind it.

Sometimes a coil will get tangled while rolling. In this case the ends should be pulled through the tangle when necessary and walked around to unwind where possible and laid out fairly straight on the ground. One end should then be twisted oppositely from the obvious kinks while jerking it up and down so that the reverse twist will get to them. If the cable is short enough so that the far end can be flipped free of the ground, this alone may straighten it without hand twisting.

Lubrication. Wire rope needs a lubricant to minimize friction between the wires. The manufacturer lubricates it thoroughly and for short cables in continuous use this is sufficient. However, if it is to lie idle for any length of time it should be oiled or greased to avoid rust damage. Also, if it wears shiny in use it should be greased for the sake of the sheaves as much as that of the cable.

Safety Factor. The safety factor in rope is the ratio between the pull required to break a new cable and the load it carries in service. Safety factors of three, five, or better in relation to normal pull, are recommended. A shovel with a five ton pull on a drag cable should use one with a tested strength of fifteen to twenty-five tons. This safety factor allows a margin for shock loads, which may be several times normal load for a moment, and permits the rope to continue working after some of its wires are weakened and broken.

Highest safety factors are required for suspended loads over or near people or valuable property.

Cable life is prolonged and required margin for shock loads is reduced in excavator service by the use of a torque converter in the power train, in spite of the increase in torque at the drum shafts.

Courtesy of Wire Rope Institute

Fig. 12-11. Cable fittings

Capacity. Drum capacity may be calculated according to Figure 12-10.

CABLE SYSTEMS

Fittings and Anchors. In general, cable ends require some sort of clamp or fitting to attach them to the power source or work. A variety of these is shown in Figures 12-11 and 12-12.

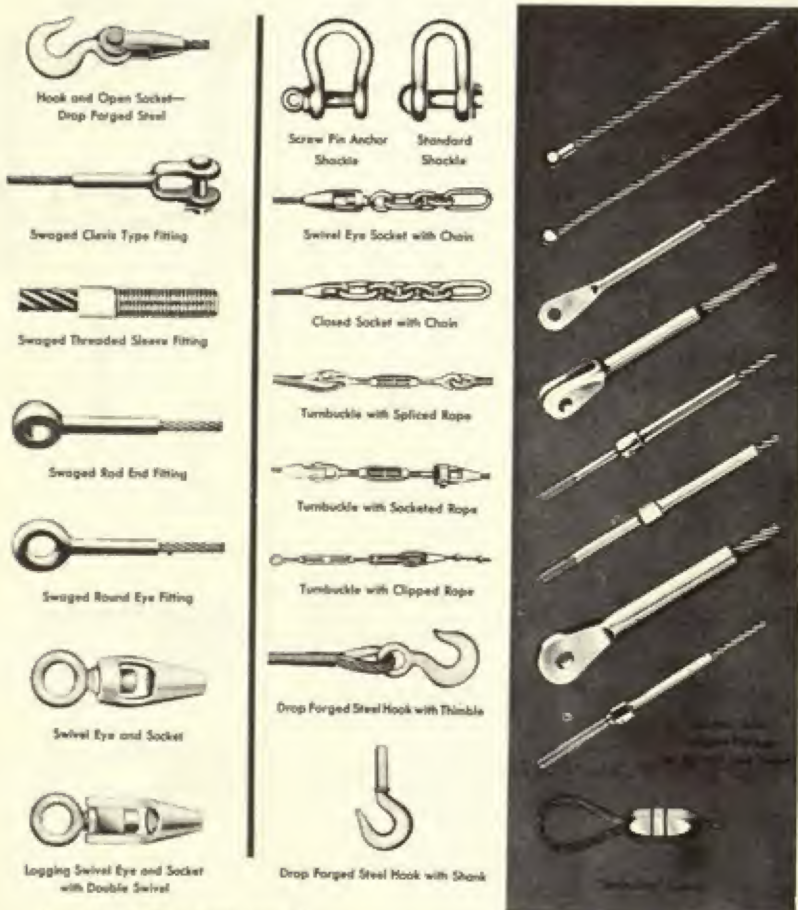
The connection between the wire rope and the fitting may be secured by clamps, wedges, or fillers.

The standard clip, or cable clamp, consists of a U-bolt, a saddle, and two nuts. The cable is doubled over on itself, and the two thicknesses squeezed between the U and the saddle by tightening nuts. The grooved inner surface of the saddle has a better grip than the U, and is therefore used on the live or working end of the rope.

There are also heavy duty types of clip that use two identical saddles with rough inside surfaces, and can be put on from either side.

Two or more clips are used, the number increasing with the diameter of the cable. They afford a good grip, but are tedious to install and remove and occupy too much space for some uses.

The wedge socket jams the cable in too-small grooves in the outer surface of the wedge and in the inner suface of the socket.



Courtesy of Wire Rope Institute

Fig. 12-12. More cable fittings

The cable is wrapped around the wedge which is tapped into the socket. Pull on the cable pulls the wedge farther, tightening the connection.

This device is best suited to excavator and other cables whose ends are more or less fixed, and which have to be removed at intervals. It is too bulky for many applications.

A poured (filled) fitting consists of a conical socket attached to an eye, loop, hook, or other device. It is installed by putting the end of the rope through the small end of the socket, fraying it out like a brush, removing the hemp center, if any, and lubricant or other foreign matter. Molten zinc is then poured in the socket. It hardens, holding the individual wires in their expanded position so that they cannot be pulled through the small end.

Babbit and lead are too soft for use in these fittings unless the load is to be extremely light.

Broken chains can be repaired by hot forging of new links or by using special repair or connecting links, two types of which are shown in Figure 12-13.

Such links are purchased assembled and separated by driving a chisel or a very sharp screwdriver between the pieces. This is most conveniently done in the shop.

If the links to be connected have pulled

out of shape it may not be possible to get the repair pieces through them. Such a link can be opened up by placing it on a block with a hole in it, and driving a big punch through it.

A good repair link is somewhat stronger than a standard chain link.

POWER PLANTS

The majority of excavating and hauling machines use gasoline or diesel engines. These are called internal combustion engines because fuel is burned inside the same unit that turns the shaft. They were given the name to distinguish them from steam engines, which burn fuel to make steam and then pipe the steam to an engine that converts it to usable power.

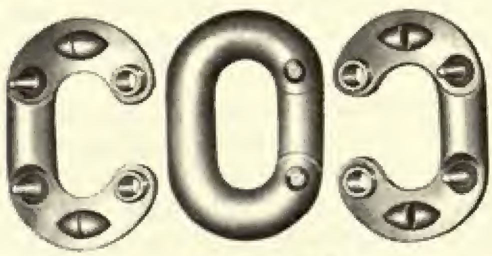
Gasoline and diesel engines have many things in common. They burn a mixture of air and fuel, turning the heat of their explosive combination into pressure against a piston on a crank that turns a shaft. They must use clean air and clean fuel, keep a film of oil on all moving parts, should be kept at an even temperature by a cooling system, and usually have a throttle to regulate speed. Industrial engines such as are used in excavators have a governor that automatically opens and closes the throttle to maintain proper speed.

Air Filter. Dust must be filtered out of air taken in by an engine to prevent it from wearing moving parts by scratching and grinding them and from building up gummy deposits by combining with the lubricating oil. Excavating machines work on dusty jobs so often that it is particularly important that they have good filters that are properly cared for.

The standard industrial air cleaner assembly includes a vertical intake pipe equipped with a dry pre-cleaner at the top and an oil or wet type cleaner at the bottom. One engine may have two or more intake pipes and cleaners.

The pre-cleaner takes in air from beneath and gives it a rotary motion by passing it over inclined vanes. The whirling air climbs around the intake pipe inside of the inner wall of a hollow case closed at the bottom, and at the top makes a sharp U-turn to get down the pipe. The spinning and the abrupt change of direction throw all the heavy particles against the outer wall of the case at the top, from where they settle down into the hollow in the case. A sight glass on one side permits the operator to see how much dirt has accumulated. When the line is about halfway up on the glass, he stops the engine, unscrews a wing nut on the holding bolt, removes a cap and then the outer case, and turns it upside down and shakes the dirt out of it. It is then replaced, with care that the gasket between the cap and the case is seating properly.

At the bottom of the pipe the air stream is turned sharply upward, blowing across the surface of an oil pool and through a maze of oil-covered wire. Particles remaining in the air after the first cleaning are caught by the oil. The oil reservoir should



MISSING LINK

Swing Link

Fig. 12-13. Repair links

be cleaned and refilled and the filter mesh cleaned and re-oiled frequently.

If the oil level is low the velocity of the air going past it will be reduced, so that more dust particles are left for the filter, which will clog rapidly. If the oil is high, too much of it may be picked up in the air stream, and some might reach the engine. In diesels, the oil will burn in the cylinders and as its amount is not controlled by the governor, it may accelerate the engine beyond its rated speed and damage it seriously. A "runaway" can be stopped by shutting off the air supply by means of a valve that is usually part of the regular shutoff mechanism, or by putting the machine in high gear and stalling it with an overload.

Altitude. High altitudes reduce the power of all internal combustion engines.

This is because the air becomes less dense as height above sea level increases. The engine therefore draws in fewer molecules with each stroke, develops lower compression, and has less oxygen to combine with fuel. Two cycle engines suffer a smaller decline up to about 10,000 feet, because their blower feed packs more air in.

Installation of a supercharger on an engine to be used at high altitudes may restore or increase its sea level power. However, the same engine with the same supercharger would show increased power if taken down to sea level.

Engines to be used entirely at high altitudes should be specially constructed and adjusted.

Fuel. The standard fuel for industrial gasoline engines is of course gasoline.

This is usually the "regular" gasoline supplied for automobiles. It includes a small quantity of tetraethyl of lead, a poisonous compound that reduces tendency to knock, and/or other chemicals to improve performance; together with a dye to give warning of the poison, or to identify make or quality.

Gasoline is classified by octane rating. Octane is an excellent fuel in anti-knock characteristics, and is given a 100% rating. Heptane is a poor anti-knock fuel and is given a 0% rating. The octane number of a gasoline is the octane percentage in a mixture of octane and heptane which it matches in antiknock value.

Commercial range now is approximately 85 to 90 for regular gasoline with additives, 91 to 95 for premium quality, and 100 to 115 for aviation gasoline.

The treated and dyed gasolines are perfectly satisfactory in industrial engines that are used regularly. However, in machines that are seldom used, such as a compressor owned by a contractor who seldom blasts, or a pump with an owner who is lucky enough to do most of his work dry, gasoline evaporates in the carburetor and lines, leaving a gummy deposit that may interfere with starting and operation, and is a nuisance to remove. However, white gasoline may be very difficult to obtain.

The chief objection to "doped" gasolines on the job is that they are poisonous, and may be very irritating to the skin, so they should not be used to clean parts, and require special care in handling. The lead may enter the body through the skin or lungs and cause cumulative poisoning, similar to painter's colic.

Leaded or doped gasoline cannot be used in engines equipped with the catalytic type of combination muffler and exhaust scrubber.

Gasoline engines can also be run on compressed butane gas, and on various special fuels available in oil production centers. Special tanks, carburetors and other equipment are needed.

The standard fuel for most diesel engines is fuel oil (diesel oil or diesel fuel oil), a petroleum distillate somewhat heavier in body and less inflammable than

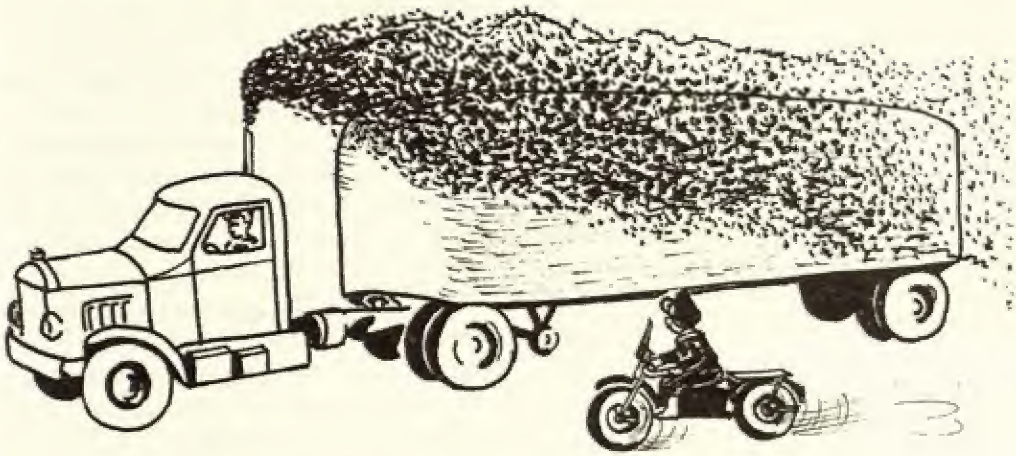


Fig. 12-14. "Souped-up" diesel on the highway

kerosene. It is almost non-volatile at ordinary temperatures. Commercial diesel fuel is usually #2 fuel oil.

Its ignition quality is rated by cetane number, and should be between 35 and 60. With varying amounts of adjustment and preparation, some diesels can burn much heavier fuels, even crude oil and the bunker C residue oils. Particular problems in handling these may include a heating device to make them fluid.

Many diesels cannot use kerosene or gasoline because they depend on fuel for lubrication of moving parts in the fuel system. Any of them may have trouble with gasoline due to pre-ignition, or vapor lock in the fuel lines.

In any grade of fuel the most important requirement is cleanliness. Many fuels contain sulphur and other corrosive chemicals in sufficient quantity to damage pumps and injectors. Any of them will have more or less foreign matter that absolutely must be strained out, as the close fits in a diesel fuel system will not tolerate any solids. It is customary to have both primary and secondary filters, and often a final one at each injector.

Second grade fuel usually increases down time and maintenance expense.

Smoke. The diesel is normally a clean burning engine, as the cylinder is charged with more than enough air to burn the maximum amount of fuel injected. It has a big advantage over gas engines in that the exhaust is almost free from carbon monoxide. However, it does exhaust some bad smelling irritating and moderately toxic gases, that prohibit its use in poorly ventilated places unless an efficient exhaust scrubber is attached.

In view of its generally clean-burning characteristics, it is unfortunate that so many diesel trucks trail clouds of black smoke behind them, to the annoyance of everyone on or near the highway. This nuisance is caused by injecting more fuel than the engine is designed to use, so that the mixture is too rich.

Excavating machines and off-the-road haulers almost never show black exhaust smoke, while all too many highway trucks put on a good imitation of a coal burning locomotive firing up. Smoking is an indication of fuel being wasted, oil being contaminated with sludge, and exhaust valves and mufflers being damaged by contact with still-burning gases. For this reason, any alert foreman or operator will send for a service man if he sees a dirty exhaust.

Some of the smoky exhausts seen on highways indicate defective parts or adjustments which will be fixed at the next service stop. Most of them, however, are a result of a driver or mechanic "souping up" or "hot-rodding" the engine by tampering with injectors or pumps, or replacing them with oversize ones designed for different service. Some increase in acceleration or power may be obtained, as the hydrogen in the fuel gets more BTUs out of the available oxygen than the carbon can, but the wasted fuel, damage to the engine, and nuisance to the public far outweigh this advantage.

If a diesel has any tendency to smoke, it will do so at wide open throttle, and particularly when lugged down below its normal operating speed. Since the same quantity of air is drawn into the cylinder regardless of throttle setting, it follows that the mixture becomes richer as the throttle is opened and more fuel is injected. At below-normal speeds, the slower piston stroke allows a considerable part of the heat of compression to be absorbed by the cylinder walls, and the resulting lower temperature flame does not use as much of the available oxygen as at higher speeds.

Starting. Diesel engines are started by cranking in much the manner of gasoline engines. However, since they depend on heat for ignition, cold starting presents a special problem. Hand cranking is impossible unless some device to relieve compression is used, and is impractical in any case.

Unit injection engines usually are cranked by an electric starter motor, powered by batteries. Voltages range from 12 to 32 or more. Motors are usually so constructed that they should not be used continuously for over 30 seconds, after which they need a minute or two to cool off. This is an unfortunate weakness, as whatever heat has been generated in the engine also dissipates during this period.

Electric-cranked engines usually need some help to start when temperatures are below freezing. This is particularly so if they are worn so that compression is poor.

The cold-starting device that appears to be most popular (with manufacturers at least) is injection of ether starting fluid into the intake passage. A dispenser or primer pump is mounted on the dash and connected by very fine tubing to a hole drilled in the intake. The pump chamber may be filled by pouring ether from a can, or by puncturing an ether capsule inserted in it. The pump handle is operated while the starter is used, so that vapor from the highly volatile ether is carried into the combustion chamber. It has a much lower flash point than fuel oil, and so will be fired by compression at a comparatively low temperature, igniting the injected fuel oil and turning the engine.

One difficulty with this device is the nuisance of getting, keeping, and using the ether. The capsules are preferable, as loss from leakage and danger of explosion are less. This fluid is so volatile and so flammable that it cannot even be stored in some localities, and it must be kept well away from heat, flame, and sparks.

Another trouble is that the tubing is so fine that it is easily damaged by vibration or accident, or closed by accidental pinching. The pump may not work properly. The tube may have drained so that by the time fresh ether from the pump reaches the air passage, a low battery may have delivered its last kick. Better average results are obtained by lifting the pre-cleaner body off the intake pipe, opening the capsule into the pipe, replacing the cleaner, then cranking the engine.

A preheater is often supplied for cold weather diesel starting. This may resemble a miniature furnace-type oil burner inside the intake passage. There is a spark plug, a nozzle, and a dashboard hand pump. The spark is switched on, fuel is forced out the nozzle and is ignited and the engine is

turned with the starter. The burner heats the air going into the cylinders. It consumes some oxygen, but usually not enough to interfere with combustion in the cylinders. The principal drawback is that mechanical difficulties, particularly shorting out the plug with fuel oil, and failure of the pump to operate, may prevent it from working when most needed.

Some preheater effect can be obtained by removing the pre-cleaner and directing the flame of a blowtorch down the intake pipe while cranking. The long distance to the cylinders causes the loss of a large part of this heat, but effects are usually good. (Note—don't ever do this with a gasoline engine, as it not only is dangerous, but it wets the spark plugs with condensation.)

Ether and a preheater must NEVER be used at the same time, as a serious explosion in the intake passage may result.

Many diesels, particularly those with precombustion chambers, must be started by an auxiliary gasoline engine. This is mounted next to the diesel, and drives it through a clutch and gears. The clutch is disengaged, the gas engine started by hand cranking or preferably with an electric starter, and run until it is warm. Cooling systems may be connected so that it warms the diesel at the same time.

The drive gears are then meshed and the clutch engaged, so that the diesel is turned over by the gas engine. It is customary to have a "start" position on the throttle, that will admit air but will not supply fuel. This permits smooth warming up without danger of running fast enough to damage the kicker engine. Finally the throttle is moved to operating position, and the clutch and/or gears disengaged.

This reduces the problem of starting the diesel to one of starting the kicker engine, but unfortunately this is often difficult. One precaution is to stop it by shutting off the fuel, rather than the ignition, so that gasoline will not be left in the carburetor and lines where it will evaporate and leave residues of lead, dyes, and other foreign materials. White gas, if obtainable, is to be greatly preferred even with this precaution.

Controls for use of the auxiliary engine may be complicated and confusing, so that sometimes it is left connected and is severely damaged by over-speeding when the diesel is revved up. An over-running clutch or a starter-type drive would avoid this danger.

One diesel is equipped with a carburetor through which the intake air can be diverted. An extra chamber with a spark plug can be connected to the main combustion chamber by opening a valve, or shut off from it by closing it.

To start cold, a change-over lever is moved to starting position, opening the auxiliary chamber to reduce compression to 6½ to 1, route air through the carburetor, and turn on the ignition. The engine is then started in the conventional manner by using choke and starter. It is run long enough to warm up the cylinders; the lever moved to shift to diesel operation, and the diesel throttle opened to the desired setting.

Many engines seem to start best when turned over by rolling, pushing, or pulling the machine rather than by using a starter. It is a very good plan to leave equipment in such position that it can be readily towed if necessary, as this may save hours of monkeying around with adjustments that might better be left for a slack time. Coasting down hill is a good means of starting, and a crawler machine may be backed up a steep pile, and started next day on a run of a few feet.

One of the few disadvantages to the increasing use of torque converters in tractors and trucks is that the slippage makes them difficult or impossible to start by towing. For cold climate use, the installation of a lockup clutch to allow solid drive might be justified on this ground alone.

In freezing weather a small quantity of

alcohol, 188 or 200 proof, should be put in the fuel tank daily. This prevents water from freezing in the lines, and enables some of it to mix with the fuel and go through the filters and engine without causing trouble. The tank should be filled at the end of the day to keep condensation at a minimum.

Oil Drag. There are four factors that make cold weather starting difficult—the extra heat required to raise fuel-air mixtures to the ignition point, the slower vaporization of fuel (particularly important with gasoline), the drag of thick cold oil on all parts, and the lowered efficiency of cold batteries.

The oil drag can be very serious. In general, thinner oils should be used in cold than in warm weather, both to reduce drag and to supply better lubrication. If conditions are severe, or particular machines are hard-starting, it is a good plan to put a small quantity of gasoline, one or two cups, in the crankcase oil filter tube just before shutting down. The engine should be turned over afterward just enough to mix the oil and gas in all its parts.

This will thin the oil so that drag will be greatly reduced the next morning. As soon as the engine warms up, the gasoline will evaporate rapidly, returning the oil to its proper viscosity. The gas vapor will escape through the crankcase breather pipe, and if it has a filter element in it, danger of fire from this source is negligible.

Wet Distributor. The problems of starting gasoline engines are well known. However, there is one excellent trick that has not received the publicity it deserves.

Difficulty in starting, and even stalling out of engines that are running can be caused by moisture inside the distributor cap. This moisture may be water that leaks in, or that condenses like dew on the inside because of atmospheric conditions or because of the outside of the cap being chilled by splashed water.

A little carbon tetrachloride (used in Pyrene fire extinguishers and as a non-explosive dry cleaning fluid) will immediately separate the water from the cap and float it. The fluid can be dumped out, the cap replaced immediately, and the engine will start unless it suffers from other ailments.

Gasoline can be used in the same way, but it is not as efficient, and must be dried out before replacing the cap, to avoid danger of explosion.

Spark plugs and ignition wires can be dried quickly by squirting carbon tetrachloride on them with a fire extinguisher.

Boosters. A battery charger is a good investment for a contractor, particularly in cold climates.

Small trickle chargers or boosters for 6 or 12 volts can be bought for less than \$20 in auto supply and mail order stores. Maximum charging rates are 4 to 10 amps, so that several hours are required to produce results. They are used chiefly for overnight and idle time day charging. No damage is done by leaving them on after the battery is charged.

Service station type units with output sufficient for quick charging cost \$50 or more, but will easily repay their cost on many jobs.

High voltage systems usually have two or more 12 volt batteries which can be detached and charged separately.

A booster cable set is made up of two insulated heavy wires similar to battery cables, which have clamps at each end. They can carry current from a good battery to the connections on a weak one, without removing either from the machine or vehicle.

One wire connects the two positive battery terminals, the other the two negatives. Both batteries should be the same voltage rating. They work together to turn the starter. As soon as the engine runs the booster cables are removed.

APPENDIX

APPENDIX

This section is made up of technical, statistical, and advisory material contributed by equipment manufacturers and associations.

Some of the production information has been gathered by them in 1956, while other parts date back as far as 1949. Figures are largely averages of actual field production, but in some cases are calculated from time and motion studies. Working conditions vary so widely that averages cannot be safely applied to any specific job. Changes and refinements in equipment may have changed its production characteristics by the time that this is read.

Because of these factors, the figures serve for general information only, and should not be used directly in estimates of production or cost, nor in comparison of different makes and models of equipment.

Unless otherwise stated, production is figured on good digging and hauling conditions, and on a 50 minute hour.

POWER SHOVEL YARDAGES

CONDITIONS:

1. Cu. yds. bank measurement per hour.
2. Suitable depth of cut for maximum effect.
3. No delays.
4. 90° swing.
5. All materials loaded into hauling units.

- Grey figures denote optimum depth of cut.
- Black figures denote yards per hour.

SHOVEL DIPPER CAPACITY IN CU. YDS.

Class of Material	3/8	1/2	3/4	1	1¼	1½	1¾	2	2½
Moist Loam or Light Sandy Clay	3.8′ 85	4.6′ 115	5.3′ 165	6.0′ 205	6.5′ 250	7.0′ 285	7.4′ 320	7.8′ 355	8.4′ 405
Sand and Gravel	3.8′ 80	4.6′ 110	5.3′ 155	6.0′ 200	6.5′ 230	7.0′ 270	7.4′ 300	7.8′ 330	8.4 390
Good Common Earth	4.5′ 70	5.7′ 95	6.8′ 135	7.8′ 175	8.5′ 210	9.2′ 240	9.7′ 270	10.2′ 300	11.2′ 350
Clay, Hard, Tough	6.0′ 50	7.0′ 75	8.0′ 110	9.0′ 145	9.8′ 180	10.7′ 210	11.5′ 235	12.2′ 265	13.3′ 310
Rock, Well Blasted	40	60	95	125	155	180	205	230	275
Common, with Rocks and Roots	30	50	80	105	130	155	180	200	245
Clay, Wet and Sticky	6.0′ 25	7.0′ 40	8.0′ 70	9.0′ 95	9.8′ 120	10.7′ 145	11.5′ 165	12.2′ 185	13.3′ 230
Rock, Poorly Blasted	15	25	50	75	95	115	140	160	195

HAUL UNITS NEEDED TO SPOT UNDER SHOVEL PER HOUR IN MEDIUM DIGGING

Size excavator dipper	Minimum haul unit capacity at 4 times dipper size	Approx. shovel cycle time in seconds 90° swing . . . no delays loading on grade	Loading time for 4-dipper truck in sec.	To synchronize loading spot one truck every	No. spots by hauling units at shovel needed per hr.
3/8	1½ yd.	19	76	1.26 min.	48 spots
½	2 yd.	19	76	1.26 min.	48 spots
¾	3 yd.	20	80	1.33 min.	45 spots
1	4 yd.	21	84	1.4 min.	43 spots
1¼	5 yd.	21	84	1.4 min.	43 spots
1½	6 yd.	23	92	1.53 min.	39 spots
2	8 yd.	25	100	1.66 min.	36 spots
2½	10 yd.	26	104	1.73 min.	35 spots

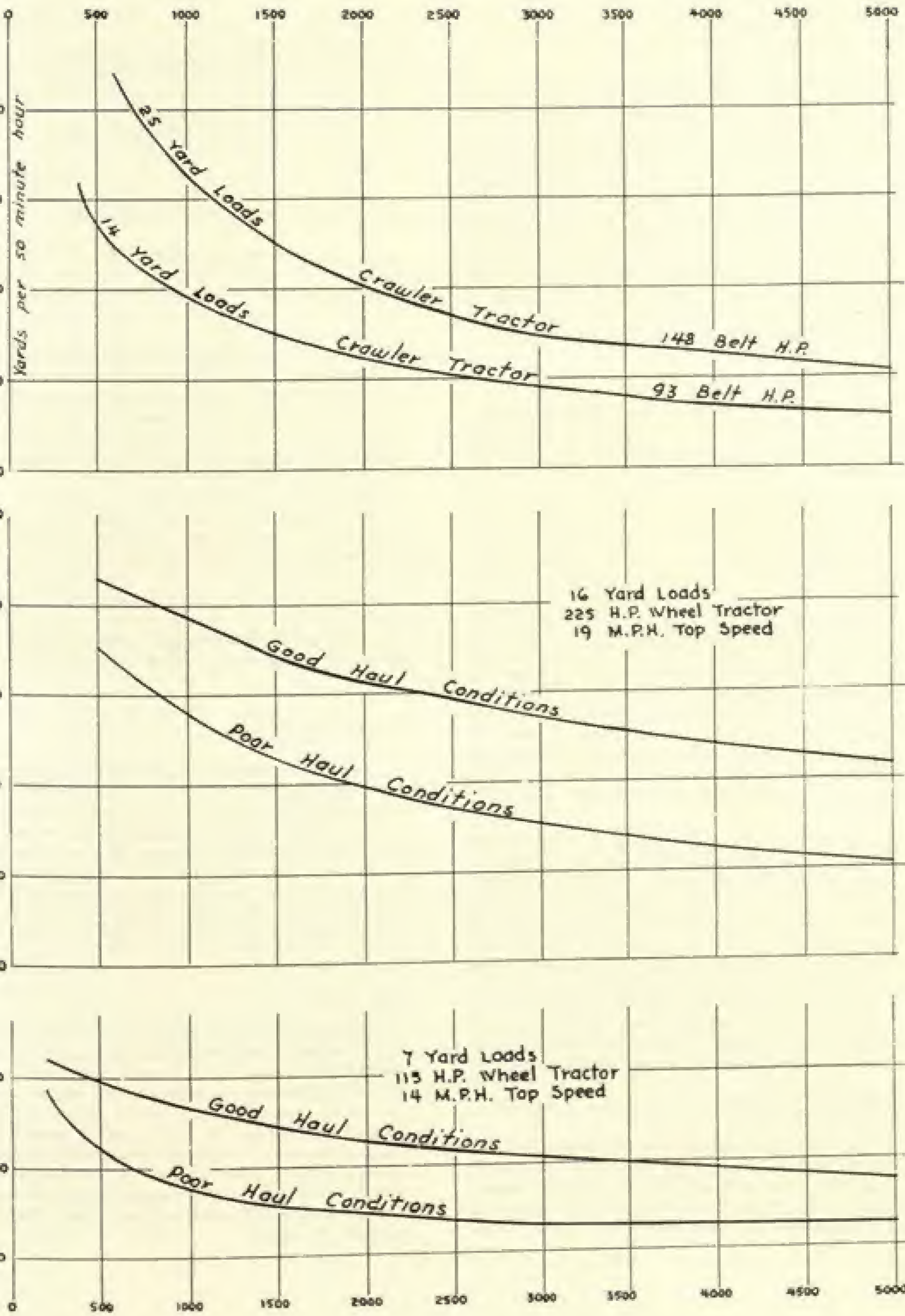
SHORT BOOM DRAGLINE PERFORMANCE—CU. YDS.

CLASS OF MATERIAL	3/8	½	¾	1	1¼	1½	1¾	2	2½
Light Moist Clay or Loam	5.0′ 70	5.5′ 95	6.0′ 130	6.6′ 160	7.0′ 195	7.4′ 220	7.7′ 245	8.0′ 265	8.5′ 305
Sand or Gravel	5.0′ 65	5.5′ 90	6.0′ 125	6.6′ 155	7.0′ 185	7.4′ 210	7.7′ 235	8.0′ 255	8.5′ 295
Good Common Earth	6.0′ 55	6.7′ 75	7.4′ 105	8.0′ 135	8.5′ 165	9.0′ 190	9.5′ 210	9.9′ 230	10.5′ 265
Clay, Hard, Tough	7.3′ 35	8.0′ 55	8.7′ 90	9.3′ 110	10.0′ 135	10.7′ 160	11.3′ 180	11.8′ 195	12.3′ 230
Clay, Wet, Sticky	7.3′ 20	8.0′ 30	8.7′ 55	9.3′ 75	10.0′ 95	10.7′ 110	11.3′ 130	11.8′ 145	12.3′ 175

NOTE: Top figure denotes optimum depth of cut. Bottom figure denotes yards per hour.

Shovel and dragline performance, 60 minute hour

SCRAPER OUTPUT



Scraper production graphs

SECTION I - OUTPUT

A.) SCRAPERS

Many contractors rely heavily on their past experience for estimating output of scrapers, bulldozers, etc. From previous jobs they have been able to formulate in their own minds output yardages for different sizes of equipment and haul lengths. Experience is a very definite asset for any contractor bidding a job - yet experience is not always enough. The contractor who has the ability to figure a job mathematically and adjust his calculations in accordance with past experience will probably be less likely to misjudge a job than one who relies only on his past experience.

TIME CYCLE

There is no mystery concerned with dirt moving operations. There are four separate functions to accomplish in any type of dirt moving operation and these are:

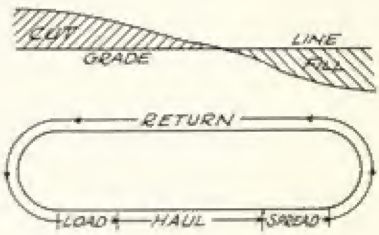
1. Dig or Load
2. Haul
3. Dump or Spread
4. Return

When the equipment has completed these four functions, it has completed a cycle. If it takes five minutes to make this complete cycle, then we have a five minute time cycle or 12 complete cycles per hour. If the equipment delivers 10 cu. yds. of dirt each cycle then in one hour it moves 120 cu. yds. If the operating expense for the equipment plus cost of supervision and profit amounts to $12.00 per hour, then the dirt is moved at a cost of 10 cents per cubic yard.

All dirt moving operations are common in that you Dig-Haul-Dump-Return to complete a cycle. From the common hand spade operated by manpower to the large scraper or dragline jobs, these four functions are ever present. In some operations the dirt may be transferred from the digging machine to another machine for transporting such as a power shovel loading into trucks. In other operations the digging machine is also the carrier such as the tractor and scraper or power shovel when the dirt is moved a short distance within dumping reach of the dipper.

PUSHER LOADING

In some job operations a pusher tractor is required to assist loading the scraper. To determine the number of scrapers one pusher tractor can handle, it is necessary to know the time cycle for both scraper outfit and pusher tractor. For



WORKING CYCLE

example, if the scrapers are running on a six minute time cycle with a pusher time cycle of 1.5 minutes (one minute to load plus 0.5 minute for pusher tractor to return to start of push) then one pusher tractor could assist four scraper outfits in loading. This would be a balanced equipment combination.

If in the same example, one pusher tractor was used for loading five scrapers, the equipment would be unbalanced and the scrapers would be held up waiting for pusher assistance. It is better to figure the time cycle in favor of the pusher tractor so that the pusher tractor may have to wait for the scraper rather than have the more expensive scraper outfit wait for the pusher.

General Contract

The contractor bids his complete job according to the subdivisions as listed on the bidding blank under the heads of CLEARING, DRAINAGE STRUCTURES, ROUGHGRADING, etc. When he comes to the point of estimating the rough grading there is certain information that is necessary for him to have. He gets his information from the plans and checks it by going over the job to see what the actual conditions are.

PAY LOAD

Payments for earth work are generally made on the basis of solid or bank measure, i.e. earth taken from the cut. When earth is removed from the cut it "swells" or increases in volume. As the earth enters the scraper it breaks up into chunks and voids are introduced. Therefore a cubic yard of earth in the cut or bank will occupy a larger volume in the scraper. After compaction in the fill the earth will generally occupy less volume than it did in its original state. This is termed shrinkage.

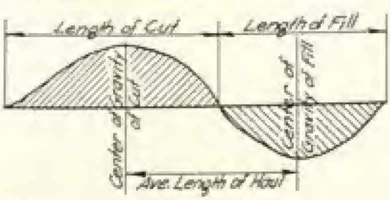
BALANCE POINTS

After analyzing the conditions of the general contract, you will find that the job is divided into several different hauls which are generally designated as "balance points." A balance point is where the amount of dirt in a cut equals the amount of compacted dirt in a fill. From this description, you can see that the general contract is divided into several small dirt moving jobs.

In some cases to equalize cut and fill material, it is necessary to "borrow" material. In these cases borrow pits are established and material is hauled from the borrow pit to the fill. In other cases where there is an excessive cut with little fill required, it is necessary to "spoil" some of the material. In these cases the material is excavated from the cut and deposited in a "spoil bank." In any case the contractor is always paid on the amount of excavation from cut or borrow pit and is never paid on the amount of fill. One exception to this method of payment is U.S. Engineer levee work where the basis for payment is volume in the fill compacted as specified in contract.

AVERAGE HAUL

This is the length of haul from the center of gravity of the cut to the center of gravity of the fill as illustrated in the following sketch.



On most jobs there is a limit as to the length or distance that the contractor is required to haul the dirt from the cut to the fill without additional payment per yard above his regular bid price. This is called the "free haul" distance. "Over haul" is the excess haul above the free haul limit. This varies in different states and generally an item is allowed for any haul beyond the free haul distance to be bid on a "cubic yard-station" basis where a station equals 100 feet.

TYPE OF DIRT (TABLE 1)

It is necessary to know the kind of dirt in each balance point, first to determine if the dirt is of a type which can be handled by a scraper,

Table 1

APPROX. PERCENTAGE OF CARRIED LOAD TO STRUCK CAPACITY FOR VARYING CLASSES OF MATERIAL FOR ESTIMATING PURPOSES

In placing the various materials in the several classes, consideration has been given to the slippage of the tractor, bulking of the material, tendency of material to bulldose ahead of cutting edge and the percentage of the bowl filled.

CLASS 1. For Est. - Use 95%	CLASS 2. For Est. - Use 85%	CLASS 3. For Est. - Use 75%
Loam	Clay	Clean Sand
Sandy loam	Heavy top soil	Small gravel
Sandy clay	Rooted rock & earth	Fine loose minerals
Packed earth	Rooted shale	Gumbo
Clay loam	White rock	Wet sticky clay
Black dirt	Rooted caliche	Cemented gravel
Clay gravel-packed		Broken rock & earth
		Hard pan and shale
		Loose gravel
		Wind blown soils

For pusher loading increase above percentages 15%

and second, to classify the dirt in accordance with Table 1 to determine the factor to use in estimating the pay load, and the weight of the load for selection of the proper gear for hauling. The pay load is the number of "in place" yards of dirt hauled in each scraper load. The size of the load obtained by a scraper and the swell or bulking of the dirt varies with the type of material being handled. Both of these factors are compensated for in the table.

Table 2

TYPES OF HAULING ROADS
A. Ordinary ground conditions which give good support to the unit.
B. Wet clay or soft ground conditions.
Any type of surface not specifically listed can undoubtedly be placed in one of these classifications with reasonable assurance that the results will be sufficiently accurate for estimating purposes. The letters A and B appearing in any of the appended tables refer in every case to these major classifications.

GROUND CONDITIONS FOR HAUL (TABLE 2)

The tractor speed is affected by the condition of the ground over which the load is hauled. Ground surfaces are classified in Table 2.

LOADING TIME (TABLE 3)

The factors that affect the loading time are the type of dirt, the length of cut, grade of cut, tractor speeds available, and the use of pusher tractors. A tractor and scraper will obtain its maximum load in each type of dirt, according to the load-

Scraper output (continued)

Table 3

APPROXIMATE TIME REQUIRED TO LOAD SCRAPERS ON THE LEVEL	
Tractor-Scraper Combinations	Time
TD-18 and B-113	1 Min.
TD-24 and B-170A	1 Min.
TD-24 and B-250 (without pusher)	1-3/4 Min.
TD-24 and B-250 with TD-24 pusher	1 Min.
Note: In the above, allowances have been made for slippage of the tractor treads, bulking of the material and ability of scraper to load to capacity in different materials.	

ing ability of the particular type of scraper. With our information on International Tractors and the digging action of International Scrapers we have been able to set up Table 3, which shows the approximate time required to load. Allowances have been made for slippage of the tractor treads, bulking of the material, ability of scraper to load to capacity in different materials and other factors. The effect of loading up a grade is generally neglected because it is customary to load down grade if possible, thereby obtaining the benefit of the added weight of the tractor to assist in loading. It is safe to assume that no one will attempt to load up a grade that the tractor cannot negotiate with a loaded scraper.

HAULING TIME (TABLES 4, 5, 6)

The time necessary to haul a load from the cut to the fill is determined by the length of the haul and by the speed at which the tractor develops sufficient horsepower to haul the loaded scraper. The speed of haul is affected by the condition of the ground over which the load is hauled, the size of the load, and the grades encountered, that is, whether hauling is on the level, up hill, or down hill.

A scraper which is "balanced" to the tractor so that the tractor will haul that scraper in high gear over good, level ground conditions, is called a balanced unit. Such a scraper is constructed as light as possible to perform the work required in order to eliminate any excessive weight which would reduce the pay load the tractor is capable of hauling.

a. Table 4 is arranged to show the drawbar pull required to haul empty and loaded scrapers on level roads.

b. Table 5 gives the drawbar pulls available for the different sizes of International tractors and the speeds that can be obtained with these pulls. Knowing the drawbar pull required (from Table 4) then the speed of haul can be determined from Table 5 both for empty and loaded scrapers.

c. Table 6 shows the additional drawbar pull needed for each 1% of grade. This additional pull must be added to the pull required on the level before tractor speeds are determined from Table 5.

BOWL FACTOR

The bowl factor is the percentage of carried load to the struck capacity and will vary depending upon type of material loaded.

APPROXIMATE OUTPUT CAPACITIES (TABLE 7)

Approximate outputs in cu. yds. per hour for the different scrapers are shown in Table 7. These outputs were calculated assuming the scraper working in Class 2 material and the loading and hauling on a level Class B road.

Table 4

DRAWBAR PULL REQUIRED TO HAUL EMPTY AND LOADED SCRAPERS ON THE LEVEL						
MODEL STRUCK CAPACITY, CU. YDS. WEIGHT OF SCRAPER EMPTY			B-113 10 22,600	B-170A 16 32,300	B-250 22 40,900	B-250* 22 50,800
Wt. Loaded Scraper (Mat. assumed 1000 lbs. per cu. yd.)		Class 1 Class 2 Class 3	51,100 48,100 45,100	77,900 73,100 68,100	104,000 97,400 90,800	113,500 106,900 100,300
Drawbar pull in lbs. required to pull Scraper on level	A	Empty Class 1 Class 2 Class 3	1,130 2,555 2,405 2,255	1,615 3,895 3,655 3,415	2,065 5,200 4,870 4,540	2,065 5,675 5,345 5,015
	B	Empty Class 1 Class 2 Class 3	2,260 5,110 4,810 4,510	3,230 7,790 7,310 6,810	4,090 10,400 9,740 9,080	4,090 11,350 10,690 10,030

NOTE: The letters "A" and "B" refer to haul roads. (See Table 2)
* = Pusher Loaded
Above drawbar pulls based on 100 lbs. per ton rolling resistance for "A" roads and 200 lbs. per ton for "B" roads.

An example for calculating the hourly output for specific conditions is shown below.

Example

Length of Haul ----------	800 feet
Type of Material --------	Clay
Haul Road --------------	Soft and rutted
Grade of haul road-------	+5%
Scraper ----------------	B-170A
Tractor -----------------	TD-24

Scraper output (continued)

SCRAPER OUTPUT

Table 1 shows clay listed as "Class 2" material with a bowl factor of 85%. Therefore, cu. yds. hauled per trip equals struck capacity rating of scraper times .85, or (16 x .85) = 13.6 cu. yds.

Table 2 shows hauling road as "B".

Table 3 gives the loading time as one minute. (In addition to loading time, one-half minute is allowed for turns.)

Table 4 gives the lbs. pull required to pull both empty and loaded scrapers on the level. For "B" haul road and Class 2 material, 7,310 lbs. drawbar pull is needed to pull loaded scraper on the level, and 3,230 lbs. drawbar pull is required to pull the scraper empty.

Table 6 shows the extra amount of drawbar pull required to haul scraper up a 1% grade. Since loaded scraper is being hauled up a 5% grade, the added drawbar pull is 1141 lbs. x 5 = 5,705 lbs. The total drawbar pull needed for hauling the loaded scraper then is 7,310 + 5,705 = 13,015 lbs.

Table 5 shows the speeds of the tractors and available pulls on "A" and "B" type roads. For this example, the TD-24 tractor will pull the loaded scraper in 4th gear which is a speed of 273 feet per min. Return trip with scraper empty can be made in 8th gear or 686 per min.

Table 5

TRACTOR PULLS AND SPEEDS

MODEL		TD-14A	TD-18A	TD-24
APPROX. OPERATING WEIGHT, LBS.		17,000	25,000	41,000
SPEEDS Feet Per Min.	1st	141	150	141
	2nd	176	194	176
	3rd	229	238	211
	4th	299	308	273
	5th	387	405	352
	6th	502	502	456
	7th	-	-	537
	8th	-	-	686
OBSERVED DRAWBAR PULL IN LBS. USE FOR CLASS "A" ROADS	1st	14,652	20,234	33,714
	2nd	11,772	15,279	26,496
	3rd	8,667	11,754	21,873
	4th	6,691	8,890	17,025
	5th	5,005	6,502	12,468
	6th	3,612	4,870	9,309
	7th	-	-	7,043
	8th	-	-	4,892
DRAWBAR PULL CLASS "B" ROADS (Observed DB pull less 75 lbs. per ton wt. of tractor for rolling resistance)	1st	14,016	19,296	32,176
	2nd	11,134	14,341	24,958
	3rd	8,029	10,816	20,335
	4th	6,053	7,952	15,487
	5th	4,367	5,564	10,950
	6th	2,974	3,932	7,771
	7th	-	-	5,505
	8th	-	-	3,354

Table 6

FACTORS FOR OPERATING ON 1% GRADE*

Multiply these factors (pounds) by the percent of grade encountered and add to drawbar pull in pounds required on the level.

COMBINATION OF EQUIPMENT	HAULING			
	EMPTY SCRAPER	LOADED SCRAPER		
		Class 1	Class 2	Class 3
TD-18A & B-113	476	761	731	701
TD-24 & B-170A	733	1189	1141	1093
TD-24 & B-250	819	1450	1384	1318
TD-24 & B-250**	819	1545	1479	1413

* Factors for 1% grade determined by taking 1% of combined weight of tractor, scraper, and load carried in scraper.

** Pusher loaded

Table 7

APPROXIMATE OUTPUT CAPACITIES

Cu. Yds. Per Hour

Length of Haul One Way Feet	EQUIPMENT		
	TD-18A B-113	TD-24 B-170A	TD-24 B-250 Pusher
100	217	366	558
200	177	306	452
300	149	263	379
400	128	231	327
500	113	205	286
600	101	185	266
700	91	169	229
800	83	155	209
900	76	143	192
1000	71	133	178
1200	66	117	154
1400	62	103	137
1600	58	94	121
1800	55	85	111
2000	52	77	104

These outputs should be obtainable with the scraper working in Class 2 material (Table 1), the loading and hauling on fairly level Class "B" road, the operator familiar with the control of the scraper and with operations based on a 50 minute hour. If the scraper is operating under more favorable conditions the figures may be increased and for hard digging or other unfavorable conditions they should be reduced.

Scraper output (continued)

Length of time cycle is the sum of loading and turning time (1.5 min.), plus hauling time ($\frac{800}{273} = 2.9$ min.), plus return time ($\frac{800}{686} = 1.2$ min.), or 5.6 minutes. Using a 50 min. hour, the number of cycles per hour is, $\frac{50}{5.6} = 8.9$ cycles per hour.

Output per hour is number of cycles (8.9) times cu. yds. hauled per trip (13.6), or 121 cu. yds/hr.

For efficient scraper operation:

1. Plan work to load scraper downhill.

2. Eliminate excess turns.

3. Load scraper in direction of where load is to be dumped.

4. Do not spend unnecessary time in trying for heaping loads - you may sacrifice this gain in cu. yds. by a longer time cycle.

5. Do not cut too deep - deep cuts increase the voids and reduce pay load. Large chunks in the scraper make poor spreading material.

6. Maintain a downslope in the cut - don't cut horizontal layers off the top.

7. On side hill cuts keep the inside of cut lower than the outside.

8. Do not allow too much slack in cables this causes unnecessary cable wear.

9. Maintain a smooth hauling road.

10. Don't raise bowl any higher than necessary when hauling - increasing bowl height reduces scraper stability.

11. Do not haul scraper with tackle block to block.

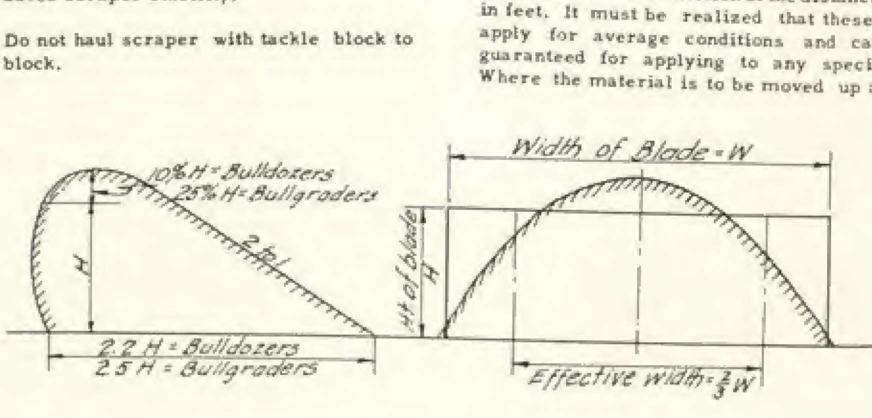
12. In constructing a fill keep shoulders high and center low - this provides drainage toward center and prevents scraper from sliding over the side of fill.

B.) BULLDOZERS AND BULLGRADERS

Data relating to estimating output and cost of operation for Bullgraders and Bulldozers has not been used extensively simply for the reason that the Bullgrader or Bulldozer has not been considered a primary dirt mover. The Bullgrader or Bulldozer on most dirt moving jobs is considered auxiliary equipment for leveling or spreading with little consideration given to its dirt moving capabilities.

However, the increasing popularity of these machines in the capacity as a primary dirt or material mover on such jobs as basement excavation, pond and drainage work, land leveling, coal handling, gravel and sand plants, etc. has caused more study of this subject. In recent years the Bullgrader and Bulldozer have changed older and less efficient methods for doing these jobs.

Sufficient data is not available on this subject yet in order to tell with reasonable accuracy the output of a Bullgrader or Bulldozer because the yardage depends on a number of variables such as the type of material moved, the size of tractor and Bulldozer or Bullgrader, the distance it is to be moved, percent of grade, etc. Since accurate figures are not available on various types of soil and materials moved, we shall be guided in this discussion by what a Bullgrader or Bulldozer can be expected to move on a level grade in average soil conditions. In the charts shown below, we have illustrated the expected output capacities for wide gauge Bullgraders and Bulldozers in cubic yards per hour as a function of the distance moved in feet. It must be realized that these charts apply for average conditions and cannot be guaranteed for applying to any specific job. Where the material is to be moved up a grade,



Bulldozer output

or where unusual digging conditions exist, the outputs will be lower than those shown in the charts. Conversely, if "Troughing" is employed and conditions are otherwise average, the outputs will be higher than those shown in the charts.

METHOD OF CALCULATING BULLDOZER AND BULLGRADER OUTPUT

Under favorable digging conditions we assume the load carried in front of the blade to approach the shape shown below. For bulldozers we assume the material will rise 10% higher than the height of the blade, and for Bullgraders 25%. These percentages are used to compensate for the difference in height of blade between a bulldozer and Bullgrader.

Using H as height of blade, W as width of blade, A as area (side view), L_1 as load carried in front of blade, and L_2 as load carried corrected to bank measure, we derive the following formulas:

Bulldozers:

$$A = \frac{1.1H \times 2.2H}{2} = \frac{2.42H^2}{2} = 1.21H^2$$

$$L_1 = 1.21H^2 \times \frac{2}{3}W = \frac{2.42H^2W}{3}$$

$$L_2 = \frac{2.42H^2W}{3} \times \frac{3}{4} = .6H^2W$$

Bullgraders:

$$A = \frac{1.25H \times 2.5H}{2} = \frac{3.12H^2}{2} = 1.56H^2$$

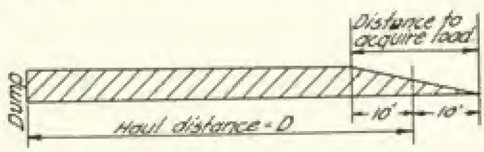
$$L_1 = 1.56H^2 \times \frac{2}{3}W = \frac{3.12H^2W}{3}$$

$$L_2 = \frac{3.12H^2W}{3} \times \frac{3}{4} = .78H^2W$$

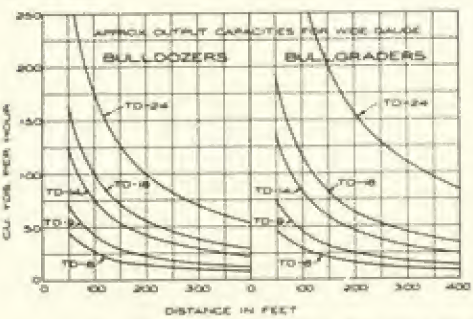
Using the formulas for L_2, the loads carried by the different size Bullgraders and bulldozers (wide gauge) are as follows:

Model	Bulldozers L_2(cu.yds.)	Bullgraders L_2(cu.yds.)
TD-6	0.70	0.75
TD-9	1.11	1.19
TD-14	1.94	2.14
TD-18	2.48	2.82
TD-24	3.88	6.08

In calculating the cubic yards per hour shown in the table below, we have assumed the tractor to be operated in first gear for pushing the load and its highest reverse gear for the return. We have also assumed that a distance of 20 feet will be required for the blade to pick up a full load. This means the bulldozer will actually travel 10 feet more than indicated for the haul distance shown.



A 50 minute hour is used allowing 10 minutes in each hour for miscellaneous work stoppages, etc. Ten seconds is allowed in each cycle for shifting gears.



APPROX. OUTPUT CAPACITY FOR WIDE GAUGE BULLDOZERS
(Cubic Yards Per Hour)

Haul (D) (Distance in Feet)	TD-6*	TD-9*	TD-14	TD-18	TD-24
50	43	68	123	163	285
100	26	41	74	99	175
150	18	29	53	70	126
200	14	22	41	55	99
250	12	19	34	45	81
300	10	16	29	38	69
350	9	14	25	33	60
400	8	12	22	29	53

APPROX. OUTPUT CAPACITY FOR WIDE GAUGE BULLGRADERS
(Cubic Yards Per Hour)

Haul (D) (Distance in Feet)	TD-6*	TD-9*	TD-14	TD-18	TD-24
50	46	73	135	185	445
100	28	44	82	113	274
150	20	31	58	80	197
200	15	24	45	62	154
250	13	20	37	51	126
300	11	17	31	44	107
350	9	15	27	38	94
400	8	13	24	33	83

* TD-6 and TD-9 tractors figured with optional reverse gear of 3.5 mph.

Bulldozer output (continued)

EUCLID LOADER PRODUCTION AND LOADING TIME

54-Inch Belt — 60 Minute Hour

	Favorable	Average	Unfavorable
Production Bank Cubic Yards per Hour	1000	750	500 to 350

	Favorable	Average	Unfavorable
Loading Time in Minutes	0.5	0.6—0.7	0.8

The highest loader production—even exceeding 1000 cu. yds. per hour—requires two pulling tractors, or one tractor pulling and another tractor pushing.

The loading time of the Euclid Loader is not directly related to hourly production figures, as in the case of shovels and draglines, since the loader works at peak capacity only while the hauling unit is being loaded. This peak capacity will be reflected in the loading time but cannot be realistically extended for hourly production figures.

The shorter loading times generally will be obtained when working with 13 cubic yard Euclid bottom-dumps. Use .7 to .8 minutes loading time for 25 cubic yard Euclid bottom-dumps (as reflected above under "unfavorable" conditions). The small difference in loading time is due to the fact that the larger bottom-dumps will generally be loaded by a loader equipped with higher horsepower engine and longer conveyor belt, and in many instances two tractors are used.

EUCLID SCRAPER LOADING

Operating Conditions	Push Loaded with Crawler Tractor	Self-Loading, Twin-Power Scraper
Favorable	.8 to 1.00 Min.	1.00 to 1.25 Min.
Average	1.20 Min.	1.50 Min.
Unfavorable	1.40 to 2.10 Min.	1.80 to 2.2 Min.

Favorable Loading Conditions	Unfavorable Loading Conditions
Topsoil	Heavy wet clay
Clay loam (not high in moisture content)	Loose sand
Sandy loam	Loose gravel
Clay (not high in moisture content)	Dense clay and shale
Compacted coal	Glacial conglomerate
Tight earth materials, if not too high in moisture content.	Rock or shale outcropping
Over 200 ft. loading area	Materials that are slippery when wet
Smooth pit	Side hill loading
Loading on down-grade	Rough, or soft borrow pits

Reproduced from "Estimating Production and Costs."

Euclid loading data

To Calculate:

swell factor of a material, divide 100 by 100 + per cent of swell.

loose cubic yard weight of a material, multiply the bank cubic yard weight by the swell factor.

bank weight per cubic yard, divide the loose weight per yard by the swell factor.

loose cubic yards payload permissible on a hauling unit, divide the rated payload capacity (in pounds) by the loose weight per cubic yard. Compare this permissible loose cubic yard payload with the heaped body capacity of the hauling unit being considered to determine the correct body size for the material. Sideboards may be added if the heaped body capacity is not sufficient to equal the rated payload (in pounds) of the hauling unit.

bank cubic yards payload permissible on a hauling unit, divide the rated payload capacity (in pounds) by bank cubic yard weight of material.

MATERIAL WEIGHTS

Material	Weight in Bank per Cubic Yard	Per cent of Swell	Swell Factor*	Loose Weight per Cubic Yard
Clay, Dry	2300 lbs.	25%	.80	1840 lbs.
Clay, Light	2800 lbs.	30%	.77	2160 lbs.
Clay, Dense, Tough or Wet	3000 lbs.	33%	.75	2250 lbs.
Coal, Anthracite	2200 lbs.	35%	.74	1630 lbs.
Coal, Bituminous	1900 lbs.	35%	.74	1400 lbs.
Earth, Dry	2800 lbs.	25%	.80	2240 lbs.
Earth, Wet	3370 lbs.	25%	.80	2700 lbs.
Earth with Sand and Gravel	3100 lbs.	18%	.85	2640 lbs.
Earth and Rock Mixture Such as Unclassified Excavation	2500-3000 lbs.	30%	.77	1920-2310 lbs.
Gravel, Dry	3250 lbs.	12%	.89	2900 lbs.
Gravel, Wet	3600 lbs.	14%	.88	3200 lbs.
Loam	2700 lbs.	20%	.83	2240 lbs.
Rock, Hard, Well Blasted	4000 lbs.	50%	.67	2680 lbs.
Rock and Stone, Crushed	3240-3920 lbs.	35%	.74	2400-2900 lbs.
Shale or Soft Rock	3000 lbs.	33%	.75	2250 lbs.

*When loading scrapers, swell factor will be about .10 higher than shown because of more compact loading.

LOADING

Loading time is dependent upon:

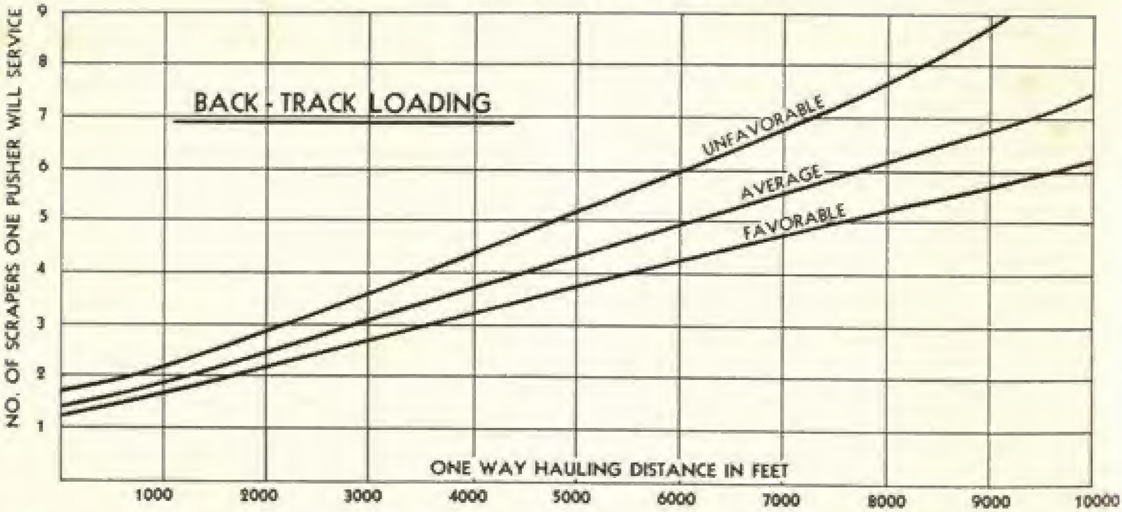
1. The size of the hauling unit.
2. Size and type of the loading machine.
3. Type and condition of the material.
4. Skill of the operator.

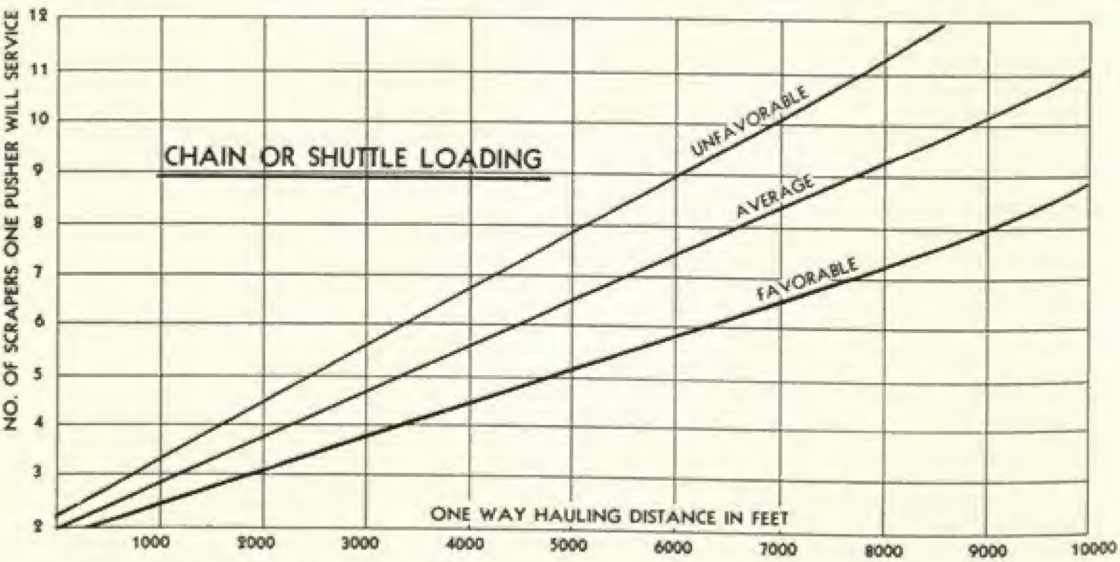
When loading with either shovels or draglines, the depth of cut and shovel swing also influence loading time. To simplify the loading time estimate, the tables covering shovels and draglines may be used.

Reproduced from "Estimating Production and Costs."

Swell factor in loading

PUSHER LOADING GRAPHS





Instructions for using the above graphs:

1. The above charts are for 15 to 20 cubic yard scrapers. For 10 to 15 cubic yard scraper increase by 10% the number of scrapers per pusher as determined from the above charts.

2. Curve No. 1 represents favorable loading and hauling conditions (3% combined grade and rolling resistance).

   Curve No. 2 represents average loading and hauling conditions (5% combined grade and rolling resistance).

   Curve No. 3 represents unfavorable loading and hauling conditions (8% combined grade and rolling resistance).

3. To determine the number of Euclid scrapers which one pusher tractor will handle, first find the haul road length at bottom of graph. (Note that this length *should not* include the distance travelled in the borrow pit and on the fill.) Next draw a vertical line up to the curve representing haul road conditions. Last draw a horizontal line from the point where the vertical and the selected curve intersect. Extend the horizontal line to the left hand margin and there read the number of scrapers that one pusher will service.

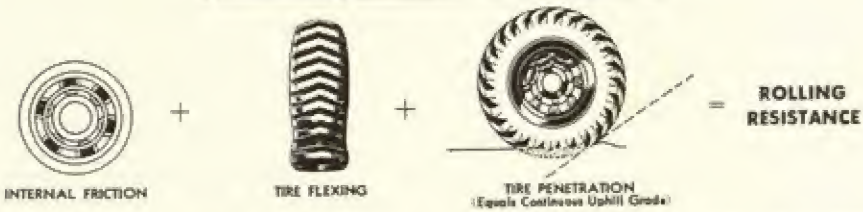
Reproduced from "Estimating Production and Costs."

Pusher loading graphs

HAULING AND RETURNING

Modern rubber-tired earth-moving equipment has great productive ability and increased performance, due to a higher horsepower-to-weight factor, and to higher average road travel speeds. These high average speeds depend on well-maintained haul roads having low rolling resistance. Total haul and return time depends upon practical road speeds attainable over various sections of the haul road, considering grades, rolling resistance, safety, and performance ability of the hauling unit.

ROLLING RESISTANCE



Rolling resistance is the resistance between the tires and level ground that must be overcome to keep the vehicle in motion. It includes resistance caused by friction in wheel bearings, by flexing of tires under load and by penetration of tires into the ground. It is normally expressed in pounds of pull, or tractive effort, required to overcome this resistance—approximately 15 lbs. of pull per 1,000 lbs. of weight on a hard surfaced road. Thus rolling resistance may be expressed as 30 lbs. per ton of gross vehicle weight, or RR = 1.5% of gross vehicle weight. The table below shows the approximate rolling resistance for various road surfaces.

In specifications covering the various Euclid models, grade ability figures allow for a rolling resistance of 40 lbs. per ton or 2%. If a rolling resistance greater than 2% is used in an estimate, subtract the difference between 2% and the actual rolling resistance from the grade ability shown in the detailed model specifications. Use the highest transmission gear showing sufficient grade ability, if this is within safe speed limits.

Type of Haul Road Surface	Pounds per Ton of Gross Vehicle	Per cent of Gross Vehicle Weight
Concrete and asphalt	30 lbs.	1.5%
Smooth, hard, dry dirt and gravel. Well maintained. Free of loose material	40 lbs.	2%
Dry dirt and gravel. Not firmly packed. Some loose material	60 lbs.	3%
Soft unplowed dirt, poorly maintained	80 lbs.	4%
Wet muddy surface on firm base	80 lbs.	4%
Snow—Packed	50 lbs.	2.5%
4" Loose	90 lbs.	4.5%
Soft, plowed dirt or unpacked dirt fills	160 lbs.	8%
Loose sand or gravel	200 lbs.	10%
Deeply rutted, or soft spongy base	320 lbs.	16%

GRADE RESISTANCE

Moving a vehicle up an incline requires tractive effort equal to the grade resistance, plus the rolling resistance encountered. The force in pounds of pull, or Tractive Effort, required to overcome the grade resistance amounts to 20 lbs. per ton of gross weight for each 1% of grade. Or, grade resistance in terms of per cent of GVW (gross vehicle weight) is the same as the per cent of grade.

Thus if a road rises vertically 6 feet for each 100 feet of horizontal advance, the per cent of grade is 6%, and the tractive effort required to overcome the grade will be 6% of gross vehicle weight.

Reproduced from "Estimating Production and Costs."

Resistance and grades

GRADE PLUS ROLLING RESISTANCE

Since grade and rolling resistance are both expressed in terms of per cent of gross vehicle weight, these may be added together for the total resistance when moving a vehicle up an incline. For example: When estimating the travel speed on an 8% grade with an estimated 4% rolling resistance, the total resistance is 12%. Subtract 2% from the 12% (since a 2% rolling resistance has been allowed in the grade ability chart in the model specifications) and check the grade ability chart in the model specifications. Select the highest transmission gear showing at least a 10% grade ability.

EFFECT OF ALTITUDE ON UNIT PERFORMANCE

Although different engine manufacturers rate the altitude performance of their engines somewhat differently, the following will be sufficiently accurate for purposes of estimating haulage:

Four-stroke diesel engines—no loss of performance up to 1000 feet above sea level. Subtract 3% in performance ability for every 1000 feet above that.

Two-stroke cycle diesel engines—Subtract 1½% in performance for every 1000 feet above sea level to 6000 ft. Above that, subtract 3% for every 1000 ft.

Example: A hauling unit equipped with a four-stroke cycle diesel engine with a grade ability of 9% at sea level. At 5000 feet its performance will decrease 4 x 3% = 12%. Reducing its sea level grade ability by 12% (9 x .12 = 1.08) we obtain the resulting grade ability at 5000 feet as 9%−1.08% = 7.9%.

AVERAGE TRAVEL SPEEDS

To estimate the hauling time, first break the haul road into sections wherever the grade, or the rolling resistance, or both, change.

After doing this, check the performance chart in the detailed model specifications for the unit under consideration. Select the proper transmission gear to overcome the grade and rolling resistance. Note the maximum travel speed shown in the selected gear for further calculations. The maximum speed must then be reduced to a practical average speed.

The following table shows the factors to establish average travel speeds over various lengths of haul.

Factors for Conversion of Maximum Speed to Average Speed

Length of Haul Road Section	Short Level Hauls 500 to 1000 Ft. Total Length	Unit Starting From Stop	Unit in Motion When Entering Haul Road Section
0 - 350 ft.	.20	.25 - .50	.50 - 2.00
350 - 750 ft.	.30	.35 - .60	.60 - .75
750 - 1500 ft.	.40	.50 - .65	.70 - .80
1500 - 2500 ft.		.60 - .70	.75 - .80
2500 - 3500 ft.		.65 - .75	.80 - .85
3500 ft. and up		.70 - .85	.80 - .90

To determine the average travel speed, multiply the maximum attainable speed by the factor opposite the correct haul road section length, unless safety considerations impose lower limits of speed.

Example: A hauling unit with standard transmission leaving the shovel and traveling 3000 ft. up a 4% grade, with 2% rolling resistance. Check the model specifications for maximum speed on a 4% grade and multiply this speed in M.P.H. by .65 to obtain the average speed.

(**Caution:** Performance charts which are given in Euclid model specifications already include 2% Rolling Resistance.)

Reproduced from "Estimating Production and Costs."

Altitude, and travel speeds

How to Select the Proper Speed Factor

In the above tables there is a margin between the lowest and highest factor. An error in the total cycle time estimate is most likely to be due to an error in estimating hauling and returning. Consequently, care should be exercised in the selection of the proper factor used to obtain the average speed. Always consider the following:

1. Starting Speed

A unit starting on a 500 ft. section of minus 2% grade on a good road will quickly get into high gear and has a chance to reach a high percentage of the maximum speed in high gear—therefore use high factors in the above table. On the other hand, the same unit starting on the same type of haul road section but only 250 ft. long and level, will hardly have time to get into high gear. Although theoretically it could travel in high gear, the low speed factor should be used.

2. Momentum on Shorter Sections

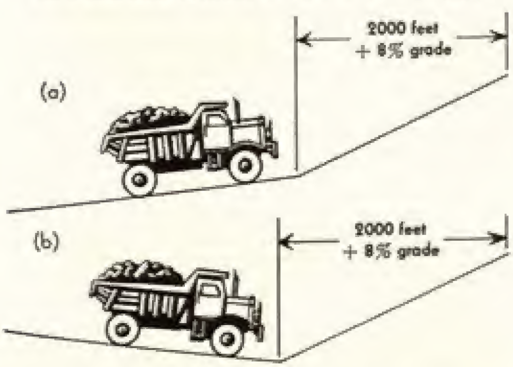
In calculating average speeds of units entering short haul road sections while already in motion the momentum has to be taken into consideration. This accounts for the wide difference in the above factors.

For example: A unit enters a +8% grade haul road section 150 ft. long while travelling 20 M.P.H. Theoretically its maximum speed on such grade would be 6 M.P.H. The momentum is likely to carry the unit over at 12 M.P.H.

3. Momentum on Longer Sections

Below is an illustration of a 2000 ft. haul road section up an 8% grade. A 15-ton Rear-Dump "Euc" would negotiate this in 3rd gear at a maximum attainable speed of 9.7 M.P.H. In case (a) the unit will be slow entering this section because of the preceding climb. In case (b) the unit will enter the 2000 ft. +8% grade section at high speed after a downhill stretch of the haul road.

Obviously, in case (b) the unit has a better chance of averaging closer to 100% of its maximum speed in 3rd gear and the high limit of the given speed factor should be used. The given figures are intended only as a guide to the majority of job conditions.



4. The Ratio of Power, Weight and Speed

Over a given section of haul road a unit that is geared slow has a better chance of attaining its top speed than a unit of equal horsepower that is geared for fast travel speeds.

Similarly a unit with a ratio of 300 lbs. per H.P. has a better chance of attaining its top speed than a unit with a ratio of 500 lbs. per H.P. provided both units are geared to travel at the same speed. This is best illustrated by the "better performance" of an empty unit against a loaded unit. The shorter the haul road section, the more noticeable will be the difference, hence the wider margin in the speed ratio tables for the shorter haul road sections.

For the purposes of estimating production with Euclids only the pounds per H.P. need be considered, and the formula at the bottom of this page can be used.

5. Units Equipped with Torque Converter

Use the high factors for haul road sections up to 1500 feet in distance.

6. Delay Factors

There are often hazards or obstructions in the haul road that slow down vehicle speed. Time allowances must be made when these conditions exist.

Intermittent Factors (Consider delay time or slow-down on each item)	**Continuous Factors** (Consider delay time or slow-down over entire haul)
One-way haul roads Delay at passing points Sharp curves	Extremely variable, and high rolling resistance
Multiple curves or switchbacks Blind corners	Wet or slippery haul roads
Bridges Underpasses Railroad crossings	Unskilled operators
Cross traffic	Long down-grade hauls

USE HIGHEST SPEED FACTOR*	when	GVW (Lbs.) / ENGINE H.P.	=	280-340 lbs./H.P.
USE AVERAGE SPEED FACTOR	when	GVW (Lbs.) / ENGINE H.P.	=	340-400 lbs./H.P.
USE LOWEST SPEED FACTOR	when	GVW (Lbs.) / ENGINE H.P.	=	400 & up lbs./H.P.

*In Table on Page 11.

Reproduced from "Estimating Production and Costs."

Gear selection

TURNING AND DUMPING

Turning and dumping time depends upon the type of hauling unit and the operating conditions. Below are averages for the different types under various operating conditions.

Turning and Dumping Time

Operating Conditions	Euclid Bottom-Dump Tractor-Trailer	Euclid Rear-Dump	Side-Dump Semi-Trailer	Euclid Scrapers
Favorable......	.3 Min.	1.0 Min.	.7 Min.	.4 Min.
Average.......	.6 Min.	1.3 Min.	1.0 Min.	.7 Min.
Unfavorable...	1.5 Min.	1.5 to 2.0 Min.	1.5 Min.	1.5 Min.

SPOT AT LOADING MACHINE

Operating Conditions	Euclid Bottom-Dump Tractor-Trailer	Euclid Rear-Dump	Side-Dump Semi-Trailer	Euclid* Scrapers	Euclid* Twin-Power Scrapers
Favorable.....	.15 Min.	.15 Min.	.15 Min.	.50 Min.	.10 Min.
Average......	.50 Min.	.30 Min.	.50 Min.	.65 Min.	.15 Min.
Unfavorable...	1.00 Min.	.50 Min.	1.00 Min.	.90 Min.	.20 Min.

*In case of scrapers, the turn-around time in the borrow pit is shown instead of spotting time for shovel loading. Average time spent waiting for pusher tractor is included for single-engine scrapers.

NUMBER OF HAULING UNITS REQUIRED

The number of hauling units required depends upon the production requirement. This may be a known, fixed quantity or it may be determined by the maximum hourly production of the loading machine. In either case the hourly production required, divided by hourly production per hauling unit, will give the theoretical number of hauling units required. Generally any fractional part of a unit more than .5 is to be considered a complete unit. A fractional part of a unit less than .5 should be carefully analyzed. Increased operating efficiency may eliminate the need for the "fraction of a unit." In other instances, particularly on small operations, the user will prefer to work a longer shift rather than to buy an extra unit. Spare or standby units are necessary if a sustained production schedule is to be maintained. The spare unit provides hauling capacity while regular maintenance or repair of units of the production fleet is performed. In average large fleet operations it is recommended that a minimum of one spare unit be provided for each group of eight.

Spare units are a very necessary and inexpensive form of production insurance. A spare unit obviously does not incur any "operating expenses" and should, therefore, be charged to the job at its "ownership cost only" as shown in Part II of this manual. The cost per cubic yard or ton hauled will be increased only slightly by having standby units—while, on the other hand, the lack of spare units can result in expensive production losses.

REQUIRED PRODUCTION

Production requirements should be clearly understood. They may be given in short tons, long tons or metric tons; in bank cubic yards or possibly loose cubic yards. In coal mines for instance the requirement may be 2000 tons of finished coal per shift, but due to waste material 2500 tons of raw coal may have to be hauled.

Reproduced from "Estimating Production and Costs."

HAULING PRODUCTION AND COST ESTIMATE

Name *Midland Construction Co.* Address *Cleveland Ohio*
Operation *Airport Const.* Production req'd. *280 Yds/Hr.* Location *Fremont Ohio*
Euclid Model *Bottom Dump* Heaped Cap. *15.1* Yds. Capacity lbs. *40,000*
Material *Common Earth* Bank Yd. *3370* lbs. Swell Factor *.80* Loose Yd. *2700* lbs.
Pay Load per Cycle; Loose Cu. Yds. *15.1* Bank Cu. Yds. *12.1* lbs. *40,770* *
Type of Loading Unit *Shovel* Bucket Size *2 1/2* No. of Passes to Load *6*
Loading Conditions *Favorable* Loading Production *(in 60 min.) 355* ~~Tons or~~ Bank Cu. Yds./Hr.

A. LOADING TIME .... *2.09* Min.

Loaded Haul—Total Length *1600 Ft.* Elevation *500* Ft.

Road Section	Length in Ft.	Rolling Resist.	Per Cent Grade	Trans. Gear	Max. Speed	Speed Factor	Average Speed	Hauling Time in Min.
Cut	*200*	*4%*	*0%*	*3*	*11.9 Mph.*	*0.35*	*4.2 Mph.*	*0.54*
Haul Road	*400*	*2%*	*4%*	*3*	*11.9 "*	*0.6*	*7.1 "*	*0.64*
Haul Road	*700*	*2%*	*0%*	*5*	*32.7 "*	*0.6*	*19.6 "*	*0.41*
Fill	*300*	*8%*	*0%*	*2*	*6.3 "*	*0.75*	*4.7 "*	*0.73*

B. TOTAL HAULING TIME *2.32* Min.

Return Empty—Total Length *1600* Ft.

Road Section	Length in Ft.	Rolling Resist.	Per Cent Grade	Trans. Gear	Max. Speed	Speed Factor	Average Speed	Return Time
Fill	*300*	*8%*	*0%*	*3*	*11.9 Mph.*	*0.5*	*5.9 Mph.*	*0.57*
Haul Road	*700*	*2%*	*0%*	*5*	*32.7 "*	*0.65*	*21.2 "*	*0.38*
Haul Road	*400*	*2%*	*-4%*	*5*	*32.7 "*	*0.7*	*22.9 "*	*0.20*
Cut	*200*	*4%*	*0%*	*5*	*32.7 "*	*0.5*	*16.3 "*	*0.14*

C. TOTAL RETURN TIME *1.29* Min.

D. Turning and Dumping—Conditions *Favorable* Turning and Dumping Time *0.30* Min.

E. Spot at Loading Machine—Conditions .... Spotting Time *0.50* Min.

F TOTAL TIME PER COMPLETE HAULING CYCLE (A+B+C+D+E) .... *6.45* Min.

G. Average Trips per Hour = $\frac{\text{50 Min. Prod. Hr.}}{\text{(F) Total Cycle Time}}$ = *7.75* Trips per Hour

H. Hourly Production = (G) Trips per Hour x Pay Load = *93.78* ~~Tons or~~ Bank Yds. per Hour

J. Number of Euclids Req'd. = $\frac{\text{Hourly Production Req'd.}}{\text{(H) Bank Yds. or Tons per Euclid per Hour}}$ = *3* Euclids

Fleet Production per Hour = J x H = *281.34* Bank Yds. ~~or Tons~~

Hauling Cost per Bank Yd. ~~or Ton~~

Hourly Cost of Owning and Operating *3* Euclids @ *\$7.23* each = *\$21.69*

Hourly Cost of Owning Spare Euclids *1* @ *\$2.65* each = *\$2.65*

K. Hourly Cost for Fleet of *4* Euclids .... Total *\$24.34*

**ESTIMATED HAULING COST PER YD. ~~OR TON~~ = $\frac{\text{K}}{\text{Fleet Production}}$ = *8.66¢* BANK YD. ~~OR TON~~

or $\frac{\text{K}}{\text{Req'd. Production}}$ = *8.69¢* BANK YD. ~~OR TON~~

*This is an important checking figure. Its relation to the rated capacity of the unit determines the need for top extensions or smaller body, should unusually light or heavy materials be handled.

**Estimate does not include overhead, profit, haul road costs, etc.

Reproduced from "Estimating Production and Costs."

Sample estimate sheet

REFERENCE FORMULAS

$$\text{GRADE ABILITY} = \frac{(972 \times \text{Foot Lbs. Eng. Torque} \times \text{T.G.R.})}{\text{R.R} \times \text{G. V. W.}} - \text{Ro Ri in } \%$$

$$\text{MAXIMUM GRADE ABILITY} = \frac{.6 \times \text{Wgt. on Drive Tires}}{\text{G. V. W.}}$$

$$\text{TRACTIVE EFFORT OR RIM PULL} = \frac{.90 \times \text{Inch Lbs. Eng. Torque} \times \text{T.G.R.} \times \text{M.E.}}{\text{R.R.}}$$

$$\text{DRAW BAR PULL} = \frac{(.90 \times \text{Inch Lbs. Eng. Torque} \times \text{T.G.R.} \times \text{M.E.})}{\text{R.R.}} - \text{Ro Ri in Lbs.}$$

$$\text{VEHICLE SPEED IN M.P.H.} = \frac{\text{Engine R.P.M.} \times \text{Tire Rolling Radius}}{168 \times \text{Total Gear Reduction}}$$

$$\text{VEHICLE SPEED IN M.P.H.} = \frac{\text{Net H.P. at Drive Wheels} \times 375}{\text{G.V.W. in Tons } (40 + 20 \times \%\ \text{Grade})}$$

Net H.P. at Drive Wheels = Max. Eng. H.P. at governed speed x .81 (for standard transmission only)

Net H.P. at Drive Wheels = Max. Eng. H.P. at governed speed x .72 (for units using torque converter)

$$\text{M.P.H.} = \frac{\text{Distance in Ft.}}{\text{Travel Time in Minutes} \times 88}$$

$$\text{ENGINE TORQUE IN LBS. FT.} = \frac{\text{H.P.} \times 5252}{\text{R.P.M.}}$$

TOTAL GEAR REDUCTION = Transmission Ratio x Overall Axle Ratio

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$$\text{AVERAGE YEARLY INVESTMENT} = \frac{\text{Initial Investment} \times (N + 1)}{2N}$$

M.P.H. = Miles per Hour
T.G.R. = Total Gear Reduction
M.E. = Mechanical Efficiency—Estimated 90%
R.R. = Tire Rolling Radius in Inches
T.E. = Tractive Effort

Ro Ri = Rolling Resistance
G.V.M. = Gross Vehicle Weight
H.P. = Horse Power
R.P.M. = Revolutions per Minute
N. = Years of Depreciation

Reproduced from "Estimating Production and Costs."

Reference formulas

WEIGHT AND MEASURE TABLES

Measure of Length

1 Mile = 1760 Yds. = 5280 Ft. = 63,360 Inches
1 Mile = 8 Furlongs = 80 Chains
1 Furlong = 10 Chains = 220 Yds.
1 Chain = 4 Rods = 22 Yds. = 66 Ft. = 100 Links
1 Rod = 5.5 Yds. = 16.5 Ft.

Measure of Length—English to Metric

1 Mile = 1.609 Kilometer
1 Yard = 0.9144 Meter
1 Foot = 0.3048 Meter = 304.8 Millimeters
1 Inch = 2.54 Centimeters = 25.4 Millimeters

Measure of Length—Metric to English

1 Kilometer = 0.6214 Mile
1 Meter = 39.37 Inch = 3.2808 Ft. = 1.0936 Yd.
1 Centimeter = 0.3937 Inch
1 Millimeter = 0.03937 Inch

Square Measure

1 Sq. Mile = 640 Acres = 6400 Sq. Chains
1 Acre = 10 Sq. Chains = 4840 Sq. Yds. = 43,560 Sq. Ft.
1 Sq. Chain = 16 Sq. Rods = 484 Sq. Yds. = 4356 Sq. Ft.
1 Sq. Rod = 30.25 Sq. Yds. = 272.25 Sq. Ft. = 625 Sq. Links
1 Sq. Yd. = 9 Sq. Ft.
1 Sq. Ft. = 144 Sq. Inches
An Acre is equal to a Square 208.7 Feet per Side

Square Measure—English to Metric

1 Sq. Mile = 2.5899 Sq. Kilometers
1 Acre = 0.4047 Hectare = 40.47 Ares
1 Sq. Yard = 0.836 Sq. Meters
1 Sq. Foot = 0.0929 Sq. Meters = 929 Sq. Centimeters
1 Sq. Inch = 6.452 Sq. Centimeters = 645.2 Sq. Millimeters

Square Measure—Metric to English

1 Sq. Kilometer = 0.3861 Sq. Mile = 247.1 Acres
1 Hectare = 2.471 Acres = 107,640 Sq. Ft.
1 Are = 0.0247 Acre = 1076.4 Sq. Ft.
1 Sq. Meter = 10.764 Sq. Ft. = 1.196 Sq. Yd.
1 Sq. Centimeter = 0.155 Sq. Inch
1 Sq. Millimeter = 0.00155 Sq. Inch

Cubic Measure

1 Cubic Yd. = 27 Cu. Ft.
1 Cubic Ft. = 1728 Cu. Inches
1 Cord = 128 Cu. Ft.
1 Gallon = 0.1137 Cu. Ft. = 231 Cu. Inches
1 Cubic Ft. = 7.48 U. S. Gallons
1 U. S. Gallon = 0.83268 Imperial Gallon
1 Imperial Gallon = 1.2009 U. S. Gallons

Cubic Measure—English to Metric

1 Cubic Yd. = 0.7646 Cubic Meters
1 Cubic Ft. = 28.316 Liters
1 Cubic Inch = 16.38 Cubic Centimeters
1 U. S. Gallon = 3.785 Liters
1 U. S. Quart = 0.946 Liters
1 U. S. Pint = 0.473 Liters
1 Imperial Gallon = 4.542 Liters

Cubic Measure—Metric to English

1 Cubic Meter = 35.314 Cu. Ft. = 1.308 Cu. Yd. = 264.2 U. S. Gallons
1 Cubic Centimeter = 0.061 Cu. Inch
1 Liter = 0.0353 Cu. Ft. = 61.023 Cu. Inches
1 Liter = 0.2642 U. S. Gallon = 1.0567 U. S. Quart

Measures of Weight—English and Metric

1 Long Ton = 2240 Lbs. = 1016.05 Kilograms
1 Short Ton = 2000 Lbs. = 907.18 Kilograms
1 Metric Ton = 2204.6 Lbs.
1 Kilogram = 2.2046 Lbs.
1 Lb. = 0.45359 Kilograms

Specific Gravity—is a number indicating how many times a certain volume of material is heavier than an equal volume of water.

ENGLISH SYSTEM—If a material has a specific gravity of 2.7 for instance, multiply this by 62.4 lbs. (weight of 1 cu. ft.) of water to obtain the weight in lbs. per cu. ft. of the material in question.

METRIC SYSTEM—If a material has a specific gravity of 2.7 for instance, multiply this by 1000 kilograms (weight of 1 cu. meter of water) to obtain the weight in kilograms per cu. meter of the material in question.

Equivalents of Density—English and Metric

1 Lb. per Cu. Yd. = 0.5933 Kg. per Cu. Meter
1 Kg. per Cu. Meter = 1.6856 Lbs. per Cu. Yd.

Equivalents of Pressure—English and Metric

1 Lb. per Sq. Inch = 0.0703 Kg. per Sq. Centimeter
1 Kg. per Sq. Centimeter = 14.244 Lbs. per Sq. Inch

Weights of Diesel Fuel

1 U. S. Gallon = 7 lbs. average.
1 U. S. Gallon = 3.17 kilograms.

Reproduced from "Estimating Production and Costs."

Weight and measure tables

GRADE TABLES

CONVERSION OF PER CENT INTO DEGREES

Per Cent	Degrees	Per Cent	Degrees
1	0°34′	21	11°52′
2	1° 9′	22	12°24′
3	1°43′	23	12°57′
4	2°18′	24	13°30′
5	2°52′	25	14° 2′
6	3°26′	26	14°34′
7	4°	27	15° 7′
8	4°34′	28	15°39′
9	5° 9′	29	16°10′
10	5°43′	30	16°42′
11	6°17′	31	17°13′
12	6°51′	32	17°45′
13	7°25′	33	18°16′
14	7°58′	34	18°47′
15	8°32′	35	19°17′
16	9° 5′	36	19°48′
17	9°39′	37	20°18′
18	10°12′	38	20°48′
19	10°45′	39	21°18′
20	11°19′	40	21°48′

CONVERSION OF DEGREES INTO PER CENT

Degrees	Per Cent	Degrees	Per Cent
1	1.75	11	19.44
2	3.49	12	21.26
3	5.24	13	23.09
4	6.99	14	24.93
5	8.75	15	26.80
6	10.51	16	28.67
7	12.28	17	30.57
8	14.05	18	32.49
9	15.84	19	34.43
10	17.63	20	36.40

Reproduced from "Estimating Production and Costs."

Grade tables

MATERIAL WEIGHTS

Material	Weight in Bank per Cubic Yard	Percent of Swell	Swell Factor	Loose Weight per Cubic Yard
Ashes, Hard Coal	700-1000 lbs.	8%	.93	650-930 lbs.
Ashes, Soft Coal with Clinkers	1000-1515 lbs.	8%	.93	930-1410 lbs.
Ashes, Soft Coal, Ordinary	1080-1215 lbs.	8%	.93	1000-1130 lbs.
Bauxite	2700-4325 lbs.	33%	.75	2020-3240 lbs.
Brick				2700 lbs.
Cement, Portland	94 lbs. per bag			
Cement, Portland	2970 lbs. (packed)	20%	.83	2450 lbs.
Coke, Lump, Loose				620-865 lbs.
Coke, Solvay, Egg, Chestnut or Pea				840 lbs.
Coke, Gas, Egg, Chestnut or Pea				785 lbs.
Coke, Gas Furnace				730 lbs.
Concrete	3240-4185 lbs.	40%	.72	2330-3000 lbs.
Concrete, Mix Wet				3500-3750 lbs.
Copper Ore	3800 lbs.	35%	.74	2800 lbs.
Gasoline, 56° Gaume	6.3 lbs. per gallon			
Granite	4500 lbs.	50 to 80%	.67 to .56	3000-2520 lbs.
Iron Ore, Hematite	6500-8700 lbs.		.45	3900 lbs.
Iron Ore, Limonite	6400 lbs.			
Iron Ore, Magnetite	8500 lbs.			
Kaolin	2800 lbs.	30%	.77	2160 lbs.
Lead Ore, Galina	12550 lbs.			
Lime				1400 lbs.
Limestone, Blasted	4200 lbs.	67 to 75%	.60 to .57	2400-2520 lbs.
Limestone, Loose, Crushed				2600-2700 lbs.
Limestone, Marble	4600 lbs.	67 to 75%	.60 to .57	2620-2760 lbs.
Mud, Dry (Close)	2160-2970 lbs.	20%	.83	1790-2460 lbs.
Mud, Wet (Moderately packed)	2970-3510 lbs.	20%	.83	2470-2910 lbs.
Oil, Crude	6.42 lbs. per gallon			
Phosphate Rock	5400 lbs.			
Sand, Dry	3250 lbs.	12%	.89	2900 lbs.
Sand, Wet	3600 lbs.	14%	.88	3200 lbs.
Sandstone	4140 lbs.	40 to 60%	.72 to .63	2980-2610 lbs.
Shale, Riprap	2800 lbs.	33%	.75	2100 lbs.
Slag, Sand	1670 lbs.	12%	.89	1485 lbs.
Slag, Solid	4320-4860 lbs.	33%	.75	3240-2640 lbs.
Slag, Crushed				1900 lbs
Slag, Furnace, Granulated	1600 lbs.	12%	.89	1430 lbs.
Slate	4590-4860 lbs.	30%	.77	3530-3740 lbs.
Trap Rock	5075 lbs.	50%	.67	3400 lbs.

Wood & Lumber

Beechwood	3250 lbs. per cord
Chestnut	2350 lbs. per cord
Elm	2350 lbs. per cord
Hemlock	2200 lbs. per cord
Hickory	4500 lbs. per cord
Pine, Norway or White	2000 lbs. per cord
Poplar	2350 lbs. per cord

Reproduced from "Estimating Production and Costs."

Material weights

SOIL CLASSIFICATION

In order to describe soils, the Public Roads Administration has investigated various soil types which exhibit characteristic field behavior. On the basis of this study soils have been divided into eight distinct classes. These classifications are sufficiently detailed so that characteristics such as compressibility, elasticity, capillary action, cohesion, shrinkage and moisture content—all extremely vital considerations to a good subgrade—can, when considered with local climatic and usage conditions, give a good index to the adequacy of the soil for a desired purpose. These eight soil classifications are as follows:

A-1—Well graded material, coarse and fine, excellent binder. Highly stable under wheel loads irrespective of moisture conditions. Functions satisfactorily when surface treated or when used as a base for relatively thin wearing courses.

A-2—Coarse and fine materials, improper grading or inferior binder. Highly stable when fairly dry. Likely to soften at high water content caused either by rains or high capillary rise from saturated lower strata, when an impervious cover prevents evaporation from top layer, or to become loose and dusty in long continued dry weather.

A-3—Coarse material only, no binder. Lacks stability under wheel loads, but is unaffected by moisture conditions. Not likely to heave because of frost, nor to shrink or expand in appreciable amounts. Furnishes excellent support for flexible pavement of moderate thickness and for relatively thin rigid pavements.

A-4—Silt soils, without coarse material, and with no appreciable amount of sticky colloidal clay. Has a tendency to absorb water very readily in quantities sufficient to cause rapid loss of stability even when not manipulated. When dry or damp presents a firm riding surface which rebounds but very little upon the removal of load. Likely to cause cracking in rigid pavements as a result of frost heaving, and failure in flexible pavements because of low supporting value.

A-5—Similar to Group A-4 but have highly elastic supporting surfaces with appreciable rebound upon removal of load even when dry. Elastic properties interfere with proper compaction of macadams during construction and with retention of good bond afterwards.

A-6—Clay soils without coarse material. In stiff or soft plastic state absorb additional water only if manipulated. May then change to a liquid state and work up into the interstices of macadams or cause failure due to sliding in high fills. Furnish firm support essential in properly compacting macadams only at stiff consistency. Deformations occur slowly and removal of load causes very little rebound. Shrinkage properties combined with alternate wetting and drying under field conditions are likely to cause cracking in rigid pavements.

A-7—Similar to Group A-6 but at certain moisture contents deforms quickly under load and rebounds appreciably upon removing of load, as do subgrades of Group A-5. Alternate wetting and drying under field conditions leads to even more detrimental volume changes than in Group A-6 subgrades. May cause concrete pavements to crack before setting and to crack and fault afterwards. May contain lime or associated chemicals productive of flocculation in soils.

A-8—Very soft peat and muck incapable of supporting a road surface without being previously compacted.

To classify a given soil, a sample is run through a series of tests to determine into which of the above groups it most closely falls. The tests to determine its classification are as follows:

1. SIEVE ANALYSIS TEST—This test determines the per cent of total quantities that will pass through seven different size sieves. Certain further checks are made to determine the distribution of material passing through a No. 40 sieve.

2. MOISTURE EQUIVALENT TEST—This test determines the per cent of weight difference between a dry sample and a moist sample.

3. LIQUID LIMIT TEST—This test is defined as the per cent of moisture at which soil changes from a plastic to a liquid condition. The test is conducted by thoroughly mixing a sample with water, smoothing it out, marking a groove in the sample and then determining the number of controlled shocks necessary to close the groove. By repeated tests it is determined what moisture content will permit the groove to close with twenty-five shocks. This moisture content is the liquid limit.

4. PLASTIC LIMIT TEST—This is defined as the per cent of moisture at which the soil changes from a solid to a plastic condition. Test is conducted by moisting a sample and rolling it into a 1/8" diameter thread with the palm of the hand. The moisture content at the time the thread begins to crumble determines the Plastic Limit.

5. PLASTICITY INDEX—The numerical difference between the liquid limit and plastic limit.

6. SHRINKAGE TEST—This test determines the "Shrinkage Limit" and the "Shrinkage Ratio". Test is conducted by putting a sample in a test bowl, drying out, and noting volume change.

$$\text{The Shrinkage Limit} = (\%\ \text{moisture content}) - \frac{(\text{Volume of dish} - \text{volume dry soil})}{\text{Weight dry soil}}\ (100)$$

$$\text{The Shrinkage Ratio} = \frac{\text{Weight of dry soil}}{\text{Volume of dry soil}}$$

7. FIELD MOISTURE CONTENT—Minimum moisture content, expressed as a percentage of the weight of the oven dried soil, at which a drop of water placed on a smoothed surface of the soil will not immediately be absorbed, but will instead spread out over the surface and give it a shiny appearance.

8. SOIL ACIDITY OR ALKALINITY—Determine pH value with colorometric test equipment. One purpose is that a lime content has certain beneficial characteristics.

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Soil classification

When the above tests have been made the results are compared by use of charts and the soil classed accordingly. Many soils will be border line cases as to classification.

Although the soil tests and resulting classification will usually give a good index to the behavior of a soil, it does not fill the need for practical soil classification terminology required by the engineer out on the job. Under field circumstances he may be able to test the soil only by visual examination. One of the common classification methods used by many engineers in the field is grouping soils by texture and structure. The terms are general and the range in any one group may be great.

These groups are as follows:

SANDY SOIL—Loose and granular soil, the individual grains of which can readily be seen or felt and may range from very fine sand to coarse sand.

CLAY SOILS—Clay soil is a fine-textured soil which forms hard lumps or clods when dry.

LOAM—A loam is a soil having a relatively even mixture of sand, silt and clay.

SANDY LOAM—A soil containing much sand but having sufficient silt and clay to render it coherent.

SILT LOAM—When this class of soil is dry and powdered, it is often called "rock flour." It is a soil having a moderate amount of fine sand and clay, over half the particles being of the size called "silt". The dry lumps are easily broken and then feel soft and floury.

CLAY LOAM—A fine-textured soil having a large percentage of clay. When dry, the clods are hard and difficult to break.

GRAVELLY OR STONY SOILS—All the above soils, if mixed with a considerable amount of pebbles, are classed as gravelly sand loams; sand clay loams; sandy clay soils, etc.

SOIL COMPACTION

The primary objective of compacting soil by sheepsfoot rollers, flat wheel rollers, pneumatic tired units, or other means is to obtain a soil of a specific density in order that it will carry specified loads without undue settlement. Much has been written on this subject, but soil types, equipment, operating conditions and moisture content are so variable that it is not practical to attempt to state definitely what work is required and what equipment is needed to get certain definite results from compaction.

The work necessary to get the desired compaction on a specific job should be determined by actual test on the job.

Soil settlement occurs under load for two reasons: (1) Air and water are expelled from the earth due to compression; and (2) The earth is forced out laterally into the surrounding soil.

Compaction operations attempt to do these things artificially by means of various types of rollers or tampers so that settlement after construction work is completed will be held to a minimum. To do this, two principles of action are involved.

1. It is necessary to place the earth in layers sufficiently thin to permit air and water to be expelled efficiently and easily. Some soils, depending upon their permeability, may be put down in thicker layers than others. For example, clay must be placed in thin layers whereas a sandy soil could be rolled in thick layers.

2. The second principle to consider is that the compression of soil particles requires movement of the individual particles in order to fit them together and fill in the voids. Before movement can take place friction must be reduced. Lubrication of the soil particles by means of moisture will help to overcome friction. Too little moisture will not materially reduce friction; too much moisture only means that the excess water must be expelled. There is, then, an optimum or ideal moisture content.

Tests have been developed for determining the adequacy of soil compaction. There is some difference in the exact procedure of tests as used by the Army Engineers and the various States, but the fundamental principles remain the same. The tests generally used are based on procedures established by the American Association of State Highway Officials (AASHO). Three main tests are used to test soil for proper compaction.

1. Moisture-content test.
2. Unit-weight determination or density test.
3. Compaction test for optimum-moisture content.

The MOISTURE CONTENT TEST (Similar to Public Roads Administration "Moisture Equivalent Test") is used to determine the ratio of the weight of the water contained in a given sample to the dry weight of the sample. The answer is expressed in per cent. The test is conducted by weighing a moist sample of earth, drying it in an oven, then noting the loss in weight due to the water evaporation. The weight of water lost divided by the weight of the dry sample and multiplied by 100 equals the per cent of moisture content.

The UNIT WEIGHT determination is a test for determining the weight of a unit volume. The answer is expressed in pounds per cubic foot.

The COMPACTION TEST FOR OPTIMUM MOISTURE CONTENT (Modified ASSHO method) is an important test used to determine what quantity of moisture in earth will permit the greatest compaction. If too much water is present more work must be done to expel the excess water. If insufficient water is present the dirt will not compact easily. This test is made by compacting in a standard test machine a quantity of the sample dirt which has been thoroughly mixed with water. After compaction the weight per unit volume of the compacted material is determined. Next, samples of the compacted earth are taken and the moisture content is determined as in the MOISTURE CONTENT TEST discussed above. From this information the moisture content for a unit weight of dirt is now known. This same procedure is repeated on several samples with varying amounts of water added until the addition of more water does not give any weight increase for a given volume. The moisture content which results in the greatest weight per volume is the OPTIMUM MOISTURE CONTENT.

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Soil compaction

The COMPACTION TEST FOR OPTIMUM MOISTURE CONTENT is similar in purpose to the STANDARD PROCTOR TEST. The two tests differ in details of procedure as to the number of dirt layers and thickness of dirt, weight of the tamper used for compacting and the distance through which the tamper is moved.

MEASURE OF ANGLES

Degrees	Rise in Inches per ft.	Rise in Inches per ft.	Degrees and Minutes	Per cent Rise in ft. per 100 ft.	Degrees and Minutes	Per cent rise in ft. per 100 ft.	Degrees and Minutes
1	.210	1/4	1° 11'	1	34.4'	36	19° 48'
2	.419	1/2	2° 23'	2	1° 8.7'	37	20° 18'
3	.629	3/4	3° 35'	3	1° 43.1'	38	20° 48'
4	.839	1	4° 46'	4	2° 17.5'	39	21° 18'
5	1.050	1 1/4	5° 56'	5	2° 51.8'	40	21° 48'
6	1.261	1 1/2	7° 7'	6	3° 26.0'	41	22° 18'
7	1.473	1 3/4	8° 18'	7	4° 0.3'	42	22° 47'
8	1.686	2	9° 28'	8	4° 34.4'	43	23° 16'
9	1.901	2 1/4	10° 37'	9	5° 8.5'	44	23° 45'
10	2.116	2 1/2	11° 46'	10	5° 42.6'	45	24° 14'
11	2.333	2 3/4	12° 54'	11	6° 16.6'	46	24° 42'
12	2.551	3	14° 2'	12	6° 50.6'	47	25° 10'
13	2.770	3 1/4	15° 9'	13	7° 24.4'	48	25° 38'
14	2.992	3 1/2	16° 15'	14	7° 58.2'	49	26° 6'
15	3.215	3 3/4	17° 21'	15	8° 31.9'	50	26° 34'
16	3.441	4	18° 26'	16	9° 5.4'	51	27° 1'
17	3.669	4 1/4	19° 30'	17	9° 38.9'	52	27° 28'
18	3.900	4 1/2	20° 33'	18	10° 12.2'	53	27° 55'
19	4.132	4 3/4	21° 36'	19	10° 45.5'	54	28° 22'
20	4.368	5	22° 37'	20	11° 18.6'	55	28° 49'
21	4.606	5 1/4	23° 38'	21	11° 51.6'	56	29° 15'
22	4.845	5 1/2	24° 37'	22	12° 24.5'	57	29° 41'
23	5.094	5 3/4	25° 36'	23	12° 57.2'	58	30° 7'
24	5.313	6	26° 34'	24	13° 29.8'	59	30° 32'
25	5.596	6 1/4	27° 31'	25	14° 2.2'	60	30° 58'
26	5.853	6 1/2	28° 27'	26	14° 34.5'	61	31° 23'
27	6.114	6 3/4	29° 22'	27	15° 6.6'	62	31° 48'
28	6.381	7	30° 16'	28	15° 38.5'	63	32° 13'
29	6.652	7 1/4	31° 8'	29	16° 10.3'	64	32° 37'
30	6.928	7 1/2	32°	30	16° 42.0'	65	33° 1'
31	7.210	7 3/4	32° 51'	31	17° 13.4'	66	33° 25'
32	7.498	8	33° 41'	32	17° 44.7'	67	33° 49'
33	7.793	8 1/4	34° 30'	33	18° 15.8'	68	34° 13'
34	8.094	8 1/2	35° 19'	34	18° 46.7'	69	34° 36'
35	8.403	8 3/4	36° 5'	35	19° 17.0'	70	35° 0'

USEFUL CONVERSION FACTORS FOR RAPID APPROXIMATION

Feet	X	.00019	= Miles
Links	X	.66	= feet
Feet	X	1.5	= links
Square inches	X	.007	= square feet
Square feet	X	.111	= square yards
Acres	X	4,840.	= square yards
Square Yards	X	.002066	= acres
Width in chains	X	8.	= acres per mile
Cubic feet	X	.04	= cu. yds. (Ap.)
Cubic inches	X	.00058	= cu. ft.
U. S. bu.	X	.046	= cu. yds.
U. S. bu.	X	1.244	= cu. ft.
U. S. bu.	X	2,150.42	= cu. in.
Cubic feet	X	.8036	= U. S. bu.
Cubic inches	X	.000466	= U. S. bu.
U. S. gals.	X	.13368	= Cu. ft.
U. S. gals.	X	231.	= cu. in.
Cubic feet	X	7.48	= U. S. gals.
Cubic inches	X	.004329	= U. S. gals.
Cylindrical feet	X	5.878	= U. S. gals.
Cylindrical in.	X	.0034	= U. S. gals.
Pounds	X	.009	= cwt. (112 lbs.)
Pounds	X	.00045	= tons (2,240 lbs.)

Example: Given seven acres of land. To find number of square yards multiply seven by 4,840. Answer: 33,880 square yards.

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TABLES OF USEFUL ENGINEERING DATA

MECHANICAL-ELECTRICAL EQUIVALENTS

Power

1 horsepower (hp = 550 foot-pounds (ft.-lb.) per second (sec.)
= 33,000 ft.-lb. per minute (min.)
= 1,980,000 ft.-lbs. per hour (hr.)
= .275 ft.-tons per sec.
= 16.5 ft.-tons per min.
= 990 ft.-tons per hr.

1 horsepower-second (hp-sec.) = 550 ft.-lb.
= .275 ft.-tons.

1 horsepower-minute (hp-min.) = 33,000 ft.-lb.
= 16.5 ft.-tons.

1 horsepower-hour (hp-hr.) = 1,980,000 ft.-lb.
= 990 ft.-tons

1 horsepower (hp) = 746 watts (w)
= .746 kilowatts (kw)

Energy

1 horsepower-hour = 2544 BTU
= .746 KW-hr.

1 Kilowatt-hour = 3413 BTU

Pressure

1 lb. per sq. in. = 2.0360" of mercury at 32° F.
= 27.71" of water at 32° F.
= 2.3091 ft. of water at 60° F.
= 144 lb. per sq. ft.

1 in. of mercury = .491 lb. per sq. in.

1 in. of water = 5.2 lb. per sq. ft. = .0361 PSI.

TABLE 13

PERCENT OF SEA LEVEL HORSEPOWER AVAILABLE FOR A FOUR CYCLE, GASOLINE OR DIESEL ENGINE FOR VARIOUS ALTITUDES

Altitude in feet	Temperature in degrees Fahrenheit 110	90	70	60	50	40	30	0	—20
0	95.4	97.1	99.1	100.0	100.8	101.8	103.9	106.2	108.5
1000	92.0	93.7	95.5	96.4	97.4	98.4	100.3	102.5	104.8
2000	88.7	90.4	92.1	93.0	93.8	94.8	96.8	98.8	101.0
3000	85.5	87.2	88.8	89.6	90.5	91.4	93.3	95.2	97.4
4000	82.5	84.0	85.6	86.5	87.3	88.2	89.9	91.8	93.8
5000	79.5	80.9	82.5	83.3	84.2	84.9	86.7	88.5	90.4
6000	76.7	78.1	79.5	80.3	81.1	82.0	83.6	85.3	87.2
7000	73.8	75.2	76.7	77.5	78.2	79.0	80.6	82.3	84.0
8000	71.2	72.5	73.9	74.6	75.4	76.2	77.6	79.3	81.1
9000	68.6	69.9	71.3	72.0	72.7	73.4	74.8	76.4	78.2
10000	66.2	67.5	68.7	69.3	70.7	70.7	72.2	73.7	75.3

TABLE 14

PERCENT OF SEA LEVEL HORSEPOWER AVAILABLE IN TRACTORS AT VARIOUS ALTITUDES POWERED BY G.M.C. TWO-CYCLE DIESEL ENGINE (APPROXIMATE ONLY)

Altitude in feet	Percent of Horsepower Available	Altitude in feet	Percent of Horsepower Available
0	100.0	6000	96.0
1000	100.0	7000	95.3
2000	99.1	8000	94.7
3000	98.2	9000	94.2
4000	97.5	10000	93.6
5000	95.8		

RULES OF THUMB

The following "Rules of Thumb" are approximately only.

ROUND TRIP HAUL TIME IN MINUTES for

$$\text{tractor-scraper} = \frac{\text{one way haul in ft.}}{100} + 1\tfrac{1}{4}.$$

THE ESTIMATED HOURLY OPERATING AND OWNERSHIP COST for a crawler tractor is equal to the delivered price multiplied by .0003 (Does not include operators wages).

GRADE RESISTANCE is equal to twenty pounds per ton of tractor weight for each 1% of grade.

THE MAXIMUM POUNDS DRAWBAR PULL of a crawler tractor is equal to 90% of its weight.

REPAIRS AND REPAIR LABOR COSTS for a crawler tractor will amount to about 100% of the delivered price of the machine based on a 5-year life of 10,000 hours.

SHEEPSFOOT COMPACTION OF SUBGRADE—continue passes until tamper "Walks itself out."

TO CORRECT ENGINE HORSEPOWER RATING FOR ALTITUDE:

1. For a gasoline or four stroke cycle engine deduct 3% from 1000 ft. of altitude above sea level.
2. For a two stroke cycle engine deduct 1% for each 1000 feet above 1000 feet.

TO CORRECT ENGINE HORSEPOWER FOR TEMPERATURES:

1. Deduct 1% of rated power at 60°F. for each 10° temperature rise.
2. Add 1% of rated power at 60°F. for each 10° temperature drop.

TABLE FOR CONVERTING PRESSURE PER SQUARE INCH INTO FEET HEAD OF WATER

Pounds per Sq. In.	Feet Head	Pounds per Sq. In.	Feet Head	Pounds per Sq. In.	Feet Head
1	2.31	45	103.90	140	323.26
2	4.62	50	115.45	150	346.34
3	6.93	55	126.99	160	369.44
4	9.24	60	138.54	170	392.53
5	11.54	65	150.08	180	415.62
6	13.85	70	161.63	190	438.71
7	16.16	75	173.17	200	461.80
8	18.47	80	184.72	225	519.52
9	20.78	85	196.26	250	577.25
10	23.09	90	207.81	275	634.97
15	34.63	95	219.35	300	692.70
20	46.18	100	230.90	325	750.42
25	57.72	110	253.99	350	808.15
30	69.27	120	277.08	375	865.87
35	80.81	125	288.62	400	923.60
40	92.36	130	300.17	500	1154.45

MILES PER HOUR IN FEET PER MINUTE AND FEET PER SECOND

Miles Per Hour	Feet Per Minute	Feet Per Second
1	88	1.46
2	176	2.94
3	264	4.4
4	352	5.87
5	440	7.33
6	528	8.8
7	616	10.26
8	704	11.73
9	792	13.2
10	880	14.67
11	968	16.13
12	1,056	17.6
13	1,144	19.07
14	1,232	20.52
15	1,320	22.00
16	1,408	23.47
17	1,496	24.93
18	1,584	26.4
19	1,672	27.86
20	1,760	29.33
21	1,848	30.8
22	1,936	32.26
23	2,024	33.72
24	2,112	35.2
25	2,200	36.67
26	2,288	38.14
27	2,376	39.6
28	2,464	41.04
29	2,552	42.50
30	2,640	44.00

ANGLES OF SLOPES

Slopes ½ to 1	= 63° 30′
Slopes ¾ to 1	= 53° 00′
Slopes 1 to 1	= 45° 00′
Slopes 1¼ to 1	= 38° 40′
Slopes 1½ to 1	= 33° 42′
Slopes 1¾ to 1	= 29° 44′
Slopes 2 to 1	= 26° 35′
Slopes 3 to 1	= 18° 25′
Slopes 4 to 1	= 14° 2′

TABLE FOR CONVERTING FEET HEAD OF WATER INTO PRESSURE PER SQUARE INCH

Feet Head	Pounds per Sq. In.	Feet Head	Pounds per Sq. In.	Feet Head	Pounds per Sq. In.
1	.43	55	23.81	190	82.37
2	.87	60	25.98	200	86.60
3	1.30	65	28.14	225	97.42
4	1.73	70	30.31	250	108.25
5	2.17	75	32.47	275	119.07
6	2.60	80	34.64	300	129.90
7	3.03	85	36.80	325	140.72
8	3.46	90	38.97	350	151.55
9	3.90	95	41.13	375	162.37
10	4.33	100	43.30	400	173.20
15	6.50	110	47.63	500	216.50
20	8.66	120	51.96	600	259.80
25	10.83	130	57.29	700	303.10
30	12.99	140	60.62	800	346.40
35	15.16	150	64.95	900	389.70
40	17.32	160	69.28	1000	433.00
45	19.49	170	73.61	....	......
50	21.65	180	77.94	....	......

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Miscellaneous information (continued)

TRAVEL TIME IN MINUTES
TRAVEL DISTANCE IN FEET

Speed in Miles Per Hour	100	200	300	400	500	600	700	800	900	1000
1.0	1.136	2.275	3.405	4.540	5.67	6.82	7.95	9.08	10.22	11.36
2.0	.568	1.136	1.705	2.275	2.84	3.41	3.98	4.55	5.12	5.68
3.0	.379	.758	1.136	1.515	1.89	2.27	2.66	3.03	3.41	3.79
4.0	.284	.568	.853	1.136	1.42	1.70	1.99	2.27	2.56	2.84
5.0	.227	.454	.682	.910	1.14	1.36	1.59	1.82	2.04	2.27
6.0	.189	.378	.568	.758	.95	1.14	1.32	1.51	1.70	1.89
7.0	.162	.324	.486	.648	.81	.97	1.14	1.30	1.46	1.62
8.0	.142	.284	.427	.570	.71	.85	.99	1.14	1.28	1.42
9.0	.126	.252	.378	.505	.63	.76	.88	1.01	1.14	1.26
10.0	.114	.227	.341	.455	.57	.68	.80	.91	1.02	1.14
11.0	.103	.206	.310	.414	.52	.62	.72	.83	.93	1.03
12.0	.095	.189	.284	.379	.47	.57	.66	.76	.85	.95
13.0	.087	.174	.262	.349	.44	.52	.61	.70	.79	.87
14.0	.081	.162	.244	.325	.41	.49	.57	.65	.73	.81
15.0	.076	.152	.227	.303	.38	.46	.53	.61	.68	.76
17.5	.065	.129	.194	.259	.32	.39	.45	.52	.58	.65
20.0	.057	.113	.170	.227	.28	.34	.40	.45	.51	.57
22.5	.050	.101	.151	.202	.25	.30	.35	.40	.45	.50
25.0	.045	.090	.136	.181	.23	.27	.32	.36	.41	.45

EXAMPLE: To estimate time required to travel 550 feet at 6.0 MPH.

First establish time for 500 ft. at 6.0 MPH .... .95
50 ft.—½ of time shown for 100 ft. at 6.0 MPH .... .09

1.04 Minutes

Enter 1.04 min. for travel time for 550 ft. at 6 MPH.

WEIGHTS AND THICKNESSES OF VARIOUS PIPE USED FOR HIGHWAY DRAINAGE

MATERIAL	DIAMETER IN INCHES							
	12	15	18	24	30	36	42	48
Corrugated Metal Gage....	16	16	16	14	14	12	12	12
Wall thickness, in..........	1/16	1/16	1/16	5/64	5/64	7/64	7/64	7/64
Weight per ft. lb..........	10.5	12.9	15.3	25.2	30.9	51.0	59.5	68.0
Spiral Corr. Cast Iron Wall Thickness, in..........			5/16	⅜	7/16	7/16		
Weight per ft. lb..........			65	90	135	180		
Vitrified Tile D.S. Wall Thickness, in..........	1	1¼	1½	2	2½	2¾		
Weight per ft. lb..........	50	65	100	80	290	385		
Cast Iron Class "B" Wall Thickness, in..........	.62	.68	.75	.89	1.03	1.15	1.28	1.42
Weight per ft. lb..........	82	115	150	233.33	333.3	454	592	750
Reinforced Concrete Wall Thickness, in..........	2	2¼	2½	3	3½	4	4½	5
Weight per ft. lb..........	88	121	164	264	378	500	655	870

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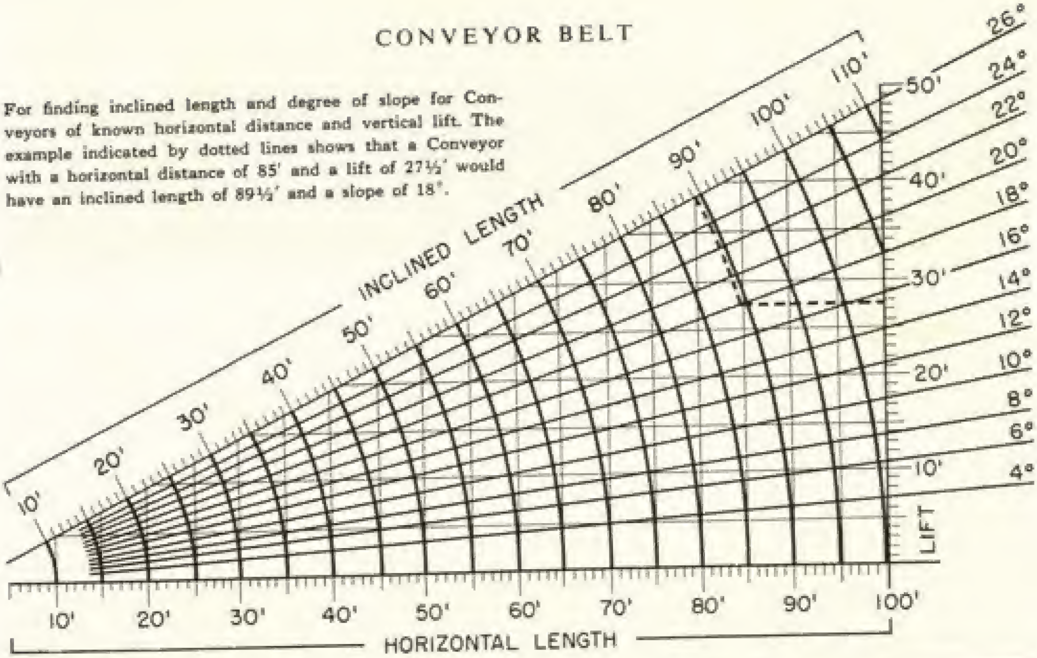
Miscellaneous information (continued)

CONVEYOR BELT

For finding inclined length and degree of slope for Conveyors of known horizontal distance and vertical lift. The example indicated by dotted lines shows that a Conveyor with a horizontal distance of 85' and a lift of 27½' would have an inclined length of 89½' and a slope of 18°.



MAXIMUM SAFE INCLINATIONS OF TROUGHED BELT CONVEYORS FOR HANDLING VARIOUS BULK MATERIAL								
MATERIAL	ANGLE	RISE PER 100 FT.	MATERIAL	ANGLE	RISE PER 100 FT.	MATERIAL	ANGLE	RISE PER 100 FT.
CEMENT-LOOSE	22°	40.4'	EARTH-LOOSE	20°	36.4'	PACKAGES-PAPER WRAP	16°	28.6'
CLAY-FINE DRY	23°	42.4'	GLASS-BATCH	21°	38.4'	ROCK-FINE CRUSHED	22°	40.4'
CLAY-WET LUMP	18°	32.5'	GRAIN	16°	28.6'	ROCK-MIXED	20°	36.4'
COAL-MINE RUN	18°	32.5'	GRAVEL-BANK RUN	18°	32.5'	ROCK-SIZED	18°	32.5'
COAL-SIZED	18°	32.5'	GRAVEL-SCREENED	15°	26.8'	SALT	20°	36.4'
COAL-BIT SLACK	23°	42.4'	GYPSUM-POWDERED	23°	42.4'	SAND-DRY	15°	26.8'
COAL-ANTHRACITE	16°	28.6'	LIME-POWDERED	23°	42.4'	SAND-DAMP	20°	36.4'
COKE-OVEN RUN	18°	32.5'	LIMESTONE	18°	32.5'	SAND-TEMPER FOUNDRY	24°	44.5'
COKE-SIZED	18°	32.5'	ORE-FINE	22°	40.4'	SULPHUR POWDERED	23°	42.4'
COKE-BREEZE	20°	36.4'	ORE-CRUSHED	20°	36.4'	WOOD-CHIPS	27°	50.9'
CONCRETE-WET	15°	26.8'	ORE-SIZED	18°	32.5'			

The horsepower required at the prime mover to drive a Belt Conveyor is the sum of these integral parts:

1. Power to move the empty Belt over the Idlers.
2. Power to move the load horizontally.
3. Power required to lift or lower the load.
4. Power to turn the pulleys.
5. Power required by Trippers.
6. Drive losses.

This may be expressed in a basic formula:

L = Length of Conveyor (feet)
S = Belt Speed (fpm)
T = Capacity (short tph)
H = Height of Lift or Drop (feet)
F_p = Pulley Friction
C = Idler Friction Factor*
Q = Weight of Moving Parts Per Ft. of Conveyor*

$$\text{Hp at Motor Shaft} = \underbrace{\frac{.03\ LSCQ}{1000}}_{\text{Empty Belt}} + \underbrace{\frac{CLT}{1000}}_{\text{Load Horiz.}} + \underbrace{\frac{TH}{1000}}_{\text{Load Lift}} + F_p + \text{Trippers} + \text{Drive Losses}$$

Belt inclination and power requirement

SUGGESTED SPEEDS WHICH ARE TODAY CONSIDERED GOOD PRACTICE FOR VARIOUS WIDTHS OF BELT HANDLING VARIOUS MATERIALS

KIND & CONDITION OF MATERIAL HANDLED	WIDTH OF BELT										
	14"	16"	18"	20"	24"	30"	36"	42"	48"	54"	60"
UNSIZED COAL, GRAVEL STONE, ASHES, ORE, OR SIMILAR MATERIAL	300'	300'	350'	350'	400'	450'	500'	550'	600'	600'	600'
SIZED COAL, COKE OR OTHER BREAKABLE MATERIAL	250'	250'	250'	300'	300'	350'	350'	400'	400'	400'	400'
GRAIN, WET OR DRY SAND..............	400'	400'	500'	600'	600'	700'	800'	800'	800'	800'	800'
CRUSHED COKE, CRUSHED SLAG OR OTHER FINE ABRASIVE MATERIAL .	250'	250'	300'	400'	400'	500'	500'	500'	500'	500'	500'
LARGE LUMP ORE, ROCK SLAG OR OTHER LARGE ABRASIVE MATERIAL. .	—	—	—	—	350'	350'	400'	400'	400'	400'	400'

TABLE 2 — CAPACITIES OF TROUGHED BELT CONVEYORS BASED ON SPEED OF 100 F.P.M. FOR VARIOUS WEIGHTS OF MATERIAL — TABLE 2

BELT WIDTH	MAXIMUM LUMPS		CAPACITY PER HOUR AT SPEED OF 100 F.P.M.								
	SIZED	UNSIZED	30# ft	50# ft	90# ft	100# ft	125# ft	150# ft	160# ft	180# ft	200# ft
14"	2"	2½"	9T	15T	28T	31T	39T	46T	49T	56T	62T
16"	2½"	3"	13T	21T	38T	42T	52T	63T	67T	75T	83T
18"	3"	4"	16T	27T	48T	54T	67T	81T	86T	97T	107T
20"	3½"	5"	20T	33T	60T	67T	83T	100T	107T	120T	133T
24"	4½"	8"	30T	50T	90T	100T	125T	150T	160T	180T	200T
30"	7"	14"	47T	79T	142T	158T	197T	236T	252T	284T	315T
36"	9"	18"	70T	117T	210T	234T	292T	351T	374T	420T	467T
42"	11"	20"	100T	167T	300T	333T	417T	500T	534T	600T	667T
48"	14"	24"	138T	230T	414T	460T	575T	690T	736T	828T	920T
54"	15"	28"	178T	297T	534T	593T	741T	890T	948T	1070T	1190T
60"	16"	30"	222T	369T	664T	738T	922T	1110T	1180T	1330T	1480T

Belt speed and capacity tables

		ENGINE						TRACTOR DIMENSIONS AND WEIGHTS (APPROXIMATE)						Number of Speeds		CAPACITIES				
	Model	Factory Equipped Price	Max. D.B. H.P.	Max. Belt H.P.	Max. Adv. H.P.	RPM Gov. @ Full Load	Piston Displa. cu. in.	Length (in.)	Height Less Pipes (in.)	Overall Width (in.) Nar.	Overall Width (in.) Wide	Ground Clearance (in.)	Wide Gauge and Weight (in.) (pounds)	Fwd.	Rev.	Cooling (Gal.)	Crankcase (Qts.)	Trans. Case (Gal.)	Final Dr. case ea. (Qts.)	Fuel Tank (Gal.)
Int'l Harv. Co.	TD-24 *	$25,750	X	X	200	1500	1091	182	96	X	102	14	80"-40,750	4	4	38	30	48	21	135
Allis Chalmers Mfg. Co.	HD-21AC*	25,140	X	X	204	1800	844	194	99	X	109	16	84"-44,000	2	1	20	24	9 3/4	30	135
Caterpillar Trac. Co.	D-9 *	35,685	X	X	286	1200	1473	214	105	X	119	21	90"-56,650	3	2	35	40	10	54	157
Caterpillar Trac. Co.	D-8 *	24,885	X	X	191	1200	1246	205	89	X	104	13	78"-41,265	3	3	25	34	7 3/4	20	118
Euclid Div. – Genrl. Mtrs.	TC-12 *	42,500	X	X	194 ea.	1800	426 ea.	194	95	X	136	20	110"-58,100	3	3	28 ea.	20 ea.	35 ea.	36	74 ea.
Int'l Harv. Co.	TD-24	23,075	161	X	190	1400	1091	182	98	X	104	14	80"-40,490	8	8	37	30	48	21	135 -
Caterpillar Trac. Co.	D-9	33,385	230	X	286	1200	1473	214	105	X	119	21	90"-56,200	6	6	35	40	15	54	157
Caterpillar Trac. Co.	D-8	22,700	155	X	191	1200	1246	195	89	X	104	13	78"-40,430	5	3	25	34	8 3/4	20	118
Int'l Harv. Co.	TD-18	15,460	103	117	124	1450	691	166	85	X	94	14	74"-28,850	6	2	15	26	6	7 1/2	75
Allis Chalmers Mfg. Co.	HD-16A	17,985	125	141	X	1600	844	178	90	X	96	14	74"-31,500	6	3	15 3/4	24	8 1/2	22	100
Allis Chalmers Mfg. Co.	HD-16AC*	19,385	X	X	150	1800	844	178	90	X	96	14	74"-31,600	3	2	17	24	8	22	100
Caterpillar Trac. Co.	D-7	15,916	102	X	128	1200	831	167	81	X	97	15	74"-26,930	5	4	17	22	10 3/4	23	85
Oliver Corp.	OC-18	19,445	133	149	161	1500	895	167	83	X	112	17	78"-32,500	4	2	15 1/2	34	26	16	66
Int'l Harv. Co.	TD-14	10,905	78.5	89.5	95	1650	461	140	79	74	91	12	74"-20,360	6	2	11	16	6	7 1/2	61
Allis Chalmers Mfg. Co.	HD-11B	10,835	75	85	90	1800	516	154	84	X	96	13	74"-20,500	6	3	10	15	6 3/4	13	60
Caterpillar Trac. Co.	D-6	11,590	75	85	X	1600	525	147	75	79	95	12	74"-17,730	5	4	14 1/2	22	10 1/2	9 1/2	48
Oliver Corp.	OD	9,330	60	74	76	1300	474	128	67	69	82	12	61"-13,750	4	2	10 1/2	16	13	Trans.	30
Int'l Harv. Co.	TD-9	6,740	54	62	X	1550	350	114	69	59	75	10	60"-11,300	5	1	9	11	5 1/2	1 1/2	33
Allis Chalmers Mfg. Co.	HD-6	7,295	45	55	X	1800	344	127	60	62	79	11	60"-12,400	5	1	6 1/2	10	3	20	40
Caterpillar Tractor Co.	D-4	7,165	48	54	X	1600	350	120	69	62	78	11	60"-10,860	5	1	11	15	4 1/2	7	30
Oliver Corp.	OC-12D	6,795	53	59	X	1750	298	109	58	58	76	12	60"-10,925	4	2	5	12	8	7	35
Int'l Harv. Co.	TD-6	5,375	34	40	X	1450	248	104	62	53	63	9	50"-7,965	5	1	10 1/2	9	4	1	20
Int'l Harv. Co.	T-6	4,475	33	39	X	1450	248	104	62	53	63	9	50"-7,325	5	1	9 1/2	9	4	1	20
Caterpillar Tractor Co.	D-2	5,595	38	43	X	1650	252	107	62	56	66	9	50"-7,600	5	1	7 1/2	14	2	4 1/2	26

* - Torque Converter

The accuracy of this information is not guaranteed.

Crawler tractor specifications, March 1956

MODEL AND DESCRIPTION	No. of Axles	CAPACITY			ENGINE H. P.	WEIGHT (Approx. Lbs.)			Approximate Factory Price Dec. 1955		STANDARD DRIVE TIRES	STEERING		WHEEL BASE Ft. – In.	SCRAPER				TRAVEL SPEEDS M.P.H.	CALCULATED RIM PULL POUNDS
		Struck Yards	Heaped Yards	Tons		Tractor	Scraper	Total	Tractor	Tractor & Scraper		Type	Turn Angle Degrees	Drive to Scraper Axle	Method of Operation	Width of Cut, Ft., In.	Max. Depth of Cut. In.	Max. Depth of Spread. In.		
INTERNATIONAL HARVESTER CO.																				
Model 75 Payscraper	2	15.0	18.5	X	262	23,360	29,300	52,660	$24,560	$36,595	24:00 x 29, 24 ply	Hydro Steer	65	22-6	Cable	9–8¾	Not Limited	21½	2.7 to 23.7	30,000
Model 55 Payscraper	2	10.0	13.0	X	172	–	–	38,740	18,940	28,275	21:00 x 25, 20 ply	Hydro-Steer	65	19-6	Cable	9–1¼	Not Limited	19	2.8 to 23.7	19,120
ALLIS-CHALMERS MFG. CO.																				
Model Ts-360 Motor Scraper	2	15.0	20.0	25.0	280	23,000	26,050	49,050	25,250	37,175	24:00 x 29, 24 ply	Hydraulic	60	22-3	Cable	9–8	10	20	3.0 to 20.0	28,000
Model TS-200 Motor Scraper	2	10.0	13.0	18.0	176	18,500	20,100	38,600	18,525	27,865	21:00 x 25, 20 ply	Hydraulic	60	19-1	Hyd.	8–6	9	17	2.5 to 21.6	21,400
CATERPILLAR TRACTOR CO.																				
DW-21 Tractor and No. 470 Scraper	2	18.0	25.0	27.5	300	25,265	31,935	57,200	24,490	41,075	29.5 x 29, 22 ply	Hydraulic	90	25-7	Cable	10–4	–	20	2.3 to 20.5	34,140
DW-20 Tractor and No. 456 Scraper	3	18.0	25.0	27.5	300	28,310	29,335	57,645	27,065	41,240	29.5 x 29, 22 ply	Hyd. Booster		23-6	Cable	10–4	–	20	2.8 to 32.1	27,890
DW-15 Tractor and No. 15 Scraper	3	10.0	12.5	16.5	186	21,155	20,465	41,620	19,115	28,845	21:00 x 25, 20 ply	Hyd. Booster		19-4	Cable	8–6	12	13¾	2.3 to 24.0	22,560
EUCLID DIVISION, GENERAL MOTORS																				
S-18 Tractor and Scraper	2	18.0	24.0	30.0	300	–	–	68,400	30,900	47,600	27.00 x 33, 30 ply	Hydraulic	90	25-3	Hyd. Cable	10–0	13½	24	5.5 to 21.4	45,600
*TS-18 Tractor and Scraper	2	18.0	24.0	30.0	218ea.	–	–	77,200	29,400	61,200	27.00 x 33, 30 ply	Hydraulic	90	25-3	Hyd. Cable	10–0	13½	24	5.9 to 25.5	57,600
*16TDT Tractor and 23SH Scraper	3	18.0	24.0	30.0	194ea.	23,900	44,300	68,000	26,280	58,315	24:00 x 25, 24 ply	Hyd. Booster		22-6	Hyd. Cable	10–0	–	24	7.6 to 31.0	62,800
22TDT Tractor and 21SH Scraper	3	15.5	21.0	24.75	300	25,900	30,400	56,300	26,555	39,975	24:00 x 25, 24 ply	Hyd. Booster		23-0	Hyd. Cable	10–0	14	33	2.6 to 26.9	34,600
23TDT Tractor and 21SH Scraper	3	15.5	21.0	24.75	300	26,500	30,400	56,900	29,525	42,945	24:00 x 25, 24 ply	Hyd. Booster		23.0	Hyd. Cable	10–0	14	33	7.5 to 30.2	23,700
S-12 Tractor and Scraper	2	12.0	16.0	20.0	218	–	–	45,170	20,500	32,350	26.50 x 25, 26 ply	Hydraulic	90	21-9	Hyd. Cable	9–6	14	27	2.7 to 28.2	24,200
77FDT Tractor and 18SH Scraper	3	12.0	16.0	20.0	218	19,900	26,000	45,900	20,465	31,250	21:00 x 25, 20 ply	Hyd. Booster		21-3	Hyd. Cable	9–7	15	29	2.7 to 28.0	24,200
S7 Tractor and Scraper	2	7.0	9.0	10.5	143	–	–	26,590	14,000	21,350	18:00 x 25, 16 ply	Hydraulic	90	17-10	Hyd. Cable	6–10	10½	20	2.7 to 24.8	15,800
LETOURNEAU WESTINGHOUSE CO.																				
Model B T-Pull and B Scraper	2	18.0	23.0	24.75	293	42,000	21,000	63,000	27,980	43,980	27:00 x 33, 30 ply	Electric	90	22-11	Elec.Cable	9–6	Not Limited	22	2.4 to 28.4	36,700
Model C T-Pull and C Scraper •	2	12.2	16.0	19.0	208	•19,740	18,160	•37,900	21,600	31,980	21:00 x 25, 24 ply	Electric	90	19-2	Elec.Cable	8–6	Not Limited	14½	2.2 to 26.0	28,400
Model C T-Pull and CL Scraper •	2	19.6	24.0	16.0	208	19,500	25,210	•44,950	19,600	31,530	21:00 x 25, 24 ply	Electric	90	21-11	Elec.Cable	10–0	Not Limited	18	7.9 to 19.0	21,500
Model D T-Pull and D Scraper	2	5.9	7.0	9.0	138	12,450	10,000	22,450	13,025	18,980	18:00 x 25, 12 ply	Electric	90	15-8	Elec.Cable	7–0	Not Limited	20½	3.13 to 28.5	13,220
WOOLDRIDGE MFG. CO.																				
Model TH-142	2	14.1	18.0	X	275	–	–	48,750			24:00 x 25, 24 ply	Hydraulic	90	21-11	Cable	9–3	Not Limited	25½	3.04 to 32.7	22,200
Model TH-090B	2	12.2	15.0	X	180	–	–	42,000			21:00 x 24, 24 ply	Hydraulic	90	21-0	Cable	8–6	19	21	3.1 to 20.4	18,885
Model TH-090	2	10.2	13.5	X	165	–	–	41,000			21:00 x 24, 24 ply	Hydraulic	90	21-0	Cable	8–6	19	21	2.8 to 18.3	18,885

* Two-engine drive, one front, one rear

• Tournamatic Transmission

The accuracy of this information is not guaranteed.

Self-powered Scraper Specifications, December 1955

APPENDIX

DON'TS

Adopted by The Institute of Makers of Explosives

May 5, 1951

For the purposes of this list of DON'TS, the terms contained therein shall be as follows:

The term "explosives" shall signify any or all of the following: dynamite, black blasting powder, pellet powder, blasting caps, and electric blasting caps.

The term "electric blasting cap" shall signify any or all of the following: instantaneous electric blasting caps, delay electric blasting caps, and delay electric igniters with blasting caps attached.

1. DON'T purchase, possess, store, transport, handle, or use explosives except in strict accordance with organizational, local, state, and federal regulations.

2. DON'T store explosives anywhere except in a magazine which is clean, dry, well ventilated, properly located, substantially constructed, and securely locked.

3. DON'T allow persons under eighteen years of age to handle or use explosives, or to be present where explosives are being handled or used.

4. DON'T leave explosives lying around where children can get them.

5. DON'T allow leaves, grass, brush, or debris to accumulate within 25 feet of an explosives magazine.

6. DON'T smoke or have matches, open lights, or other fire or flame, in or near an explosives magazine, or have them nearby while handling or loading explosives.

7. DON'T shoot into explosives with any firearm, or allow shooting in the vicinity of an explosives magazine.

8. DON'T store any metallic tools or implements in an explosives magazine.

9. DON'T drop, throw, or slide packages of explosives or handle them roughly in any manner.

10. DON'T open kegs or cases of explosives in a magazine.

11. DON'T open kegs or wooden cases of explosives with metallic tools. Use a wooden wedge and wooden, rubber, or fiber mallet. Metallic slitters may be used for opening fiberboard cases, provided that the metallic slitter does not come in contact with the metallic fasteners of the case.

12. DON'T store or leave packages of explosives which have been opened without replacing the cover.

13. DON'T use empty explosives cases for kindling.

14. DON'T permit any paper product used in the packing of explosives to leave your possession. Accumulations of fiberboard cases, paper case liners, cartons, or cartridge paper should be destroyed by burning after they have been carefully examined to make sure that they are empty.

15. DON'T use explosives that are obviously deteriorated.

16. DON'T attempt to reclaim or use fuse, blasting caps, electric blasting caps or any other explosives that have been water-soaked, even if they have dried out. Consult the manufacturer.

17. DON'T carry explosives in pockets of clothing.

18. DON'T make up primers of explosives in a magazine or near excessive quantities of explosives.

19. DON'T force cartridges of any explosives into a borehole or past any obstructions in a borehole.

20. DON'T allow explosives, or drilled holes while being loaded with explosives, to be exposed to sparks from steam shovels, locomotives, or any other source.

21. DON'T spring a borehole near another hole loaded with explosives.

22. DON'T load a sprung borehole with another charge of explosives until it has cooled sufficiently.

23. DON'T tamp with metallic bars or tools. Use only a wooden stick with no exposed metal parts.

24. DON'T use combustible material for stemming.

25. DON'T allow near the danger area of a blast any persons not essential to the blasting operations.

26. DON'T fire a blast until all surplus explosives are in a safe place, all persons and vehicles are at a safe distance or under sufficient cover, and until adequate warning has been given.

27. DON'T return to the face until the smoke and fumes from the blast have been dissipated by adequate ventilation.

28. DON'T attempt to investigate a misfire too soon. Follow all applicable rules and regulations, or, if no rules are in effect, wait at least an hour.

29. DON'T drill, bore, or pick out a charge of explosives that has misfired. Misfires should be handled only by a competent and experienced man.

30. DON'T abandon any explosives. Dispose of or destroy them in strict accordance with the methods recommended by the manufacturer.

31. DON'T store cases of dynamite so that the cartridges stand on end.

32. DON'T leave dynamite, black blasting powder, or pellet powder in a field or any place where livestock can get at them.

33. DON'T take surplus quantities of permissible dynamite, black blasting powder, or pellet powder into a mine at any one time. These explosives deteriorate rapidly in a damp atmosphere.

34. DON'T use black blasting powder or pellet powder with permissible explosives or dynamite, nor dynamite with permissible explosives, in the same borehole in a coal mine.

35. DON'T tamp pellet powder in a borehole hard enough to crush the pellets, because of danger of premature explosion.

36. DON'T store blasting caps or electric blasting caps in the same box, container, or magazine with other explosives.

37. DON'T leave blasting caps or electric blasting caps exposed to the direct rays of the sun.

38. DON'T insert a wire, a nail, or any other implement into the open end of a blasting cap to remove it from a box.

39. DON'T strike, tamper with, or attempt to remove or investigate the contents of a blasting cap or an electric blasting cap.

40. DON'T try to pull the wires out of an electric blasting cap.

41. DON'T connect blasting caps or electric blasting caps to "Primacord" except by the methods recommended by the manufacturer.

42. DON'T attempt to fire a circuit of electric blasting caps except by an adequate quantity of delivered current.

43. DON'T use in the same circuit electric blasting caps made by more than one manufacturer.

44. DON'T handle explosives during the approach or progress of an electrical storm. All persons should retire to a place of safety.

45. DON'T make electrical connections without first making sure that the ends of the wires are bright and clean.

46. DON'T allow electrical connections to come in contact with other connections, bare wire, rails, pipes, the ground, or other possible sources of current or paths of leakage.

47. DON'T have electric wires or cables of any kind near electric blasting caps or boreholes charged with explosives except at the time of, and for the purpose of, firing the blast.

48. DON'T use electric blasting caps in very wet work unless they have adequate water resistance and suitably insulated leg wires.

49. DON'T use any means other than a blasting galvanometer containing a silver chloride cell for testing electric blasting caps, singly or when connected in a circuit.

50. DON'T use damaged leading or connecting wire in blasting circuits.

51. DON'T use duplex leading wire except for single shot firing.

52. DON'T tamper with or change the circuit of a blasting machine in any way for any purpose.

53. DON'T spare force or energy in operating a blasting machine.

54. DON'T store fuse or fuse lighters in a wet or damp place, or near oil, gasoline, kerosene, distillates, or similar solvents.

55. DON'T store fuse near radiators, steam pipes, boilers, or stoves.

56. DON'T handle fuse carelessly in cold weather. If possible it should be warmed slightly before using to avoid cracking the waterproof coat.

57. DON'T use short fuse. Cut fuse long enough to extend beyond the collar of the hole and to allow time to retire safely from the blast. Never use less than two feet.

58. DON'T cut fuse until you are ready to insert it into a blasting cap. Cut off an inch or two to insure a dry end.

59. DON'T cut fuse on a slant. Cut it square across with a clean, sharp blade. Seat the fuse lightly against the cap charge and avoid twisting after it is in place.

60. DON'T crimp blasting caps to fuse with a knife or with the teeth. Use a standard cap crimper and make sure that the cap is securely fastened to the fuse.

61. DON'T use fuse and blasting caps in wet work without having a thoroughly waterproof joint between the fuse and cap.

62. DON'T kink fuse in making up primers or in tamping a charge.

63. DON'T hold the primer cartridge in the hand when lighting fuse.

64. DON'T light fuse in any borehole until the holes contain sufficient stemming to protect explosives from sparks from the end spit of fuse or a flying match head.

65. DON'T try to light fuse with burning paper, other inflammable refuse, or improvised torches.

66. DON'T light fuse near blasting caps or any explosives, other than those being used in the blast.

HANDLING AND STORAGE

American Table of Distances for Storage of Explosives

As Revised and Approved by The Institute of Makers of Explosives
January 30, 1953

EXPLOSIVES		DISTANCES IN FEET WHEN STORAGE IS BARRICADED				EXPLOSIVES		DISTANCES IN FEET WHEN STORAGE IS BARRICADED			
Pounds Over	Pounds Not Over	Inhabited Buildings	Passenger Railways	Public Highways	Separation of Magazines	Pounds Over	Pounds Not Over	Inhabited Buildings	Passenger Railways	Public Highways	Separation of Magazines
2	5	70	30	30	6	500	600	340	135	135	31
5	10	90	35	35	8	600	700	355	145	145	32
10	20	110	45	45	10	700	800	375	150	150	33
20	30	125	50	50	11	800	900	390	155	155	35
30	40	140	55	55	12	900	1,000	400	160	160	36
40	50	150	60	60	14	1,000	1,200	425	170	165	39
50	75	170	70	70	15	1,200	1,400	450	180	170	41
75	100	190	75	75	16	1,400	1,600	470	190	175	43
100	125	200	80	80	18	1,600	1,800	490	195	180	44
125	150	215	85	85	19	1,800	2,000	505	205	185	45
150	200	235	95	95	21	2,000	2,500	545	220	190	49
200	250	255	105	105	23	2,500	3,000	580	235	195	52
250	300	270	110	110	24	3,000	4,000	635	255	210	58
300	400	295	120	120	27	4,000	5,000	685	275	225	61
400	500	320	130	130	29	5,000	6,000	730	295	235	65

NOTE 1—"Explosives" means any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion, *i.e.*, with substantially instantaneous release of gas and heat, unless such compound, mixture, or device is otherwise specifically classified by the Interstate Commerce Commission.

NOTE 2—"Magazine" means any building or structure, other than an explosives manufacturing building, used for the storage of explosives.

NOTE 3—"Natural Barricade" means natural features of the ground, such as hills, or timber of sufficient density that the surrounding exposures which requise protection cannot be seen from the magazine when the trees are bare of leaves.

NOTE 4—"Artificial Barricade" means an artificial mound or revetted wall of earth of a minimum thickness of three feet.

NOTE 5—"Barricaded" means that a building containing explosives is effectually screened from a magazine, building, railway, or highway, either by a natural barricade, or by an artificial barricade of such height that a straight line from the top of any sidewall of the building containing explosives to the eave line of any magazine, or building, or to a point twelve feet above the center of a railway or highway, will pass through such intervening natural or artificial barricade.

NOTE 6—When a building containing explosives is not barricaded, the distances shown in the Table should be doubled.

NOTE 7—"Inhabited Building" means a building regularly occupied in whole or in part as a habitation for human beings, or any church, schoolhouse, railroad station, store, or other structure where people

Courtesy of The Institute of Makers of Explosives

Table of distances for explosives storage

HANDLING AND STORAGE

EXPLOSIVES		DISTANCES IN FEET WHEN STORAGE IS BARRICADED				EXPLOSIVES		DISTANCES IN FEET WHEN STORAGE IS BARRICADED			
Pounds Over	Pounds Not Over	Inhabited Buildings	Passenger Railways	Public Highways	Separation of Magazines	Pounds Over	Pounds Not Over	Inhabited Buildings	Passenger Railways	Public Highways	Separation of Magazines
6,000	7,000	770	310	245	68	75,000	80,000	1,695	690	510	165
7,000	8,000	800	320	250	72	80,000	85,000	1,730	705	520	170
8,000	9,000	835	335	255	75	85,000	90,000	1,760	720	530	175
9,000	10,000	865	345	260	78	90,000	95,000	1,790	730	540	180
10,000	12,000	875	370	270	82	95,000	100,000	1,815	745	545	185
12,000	14,000	885	390	275	87	100,000	110,000	1,835	770	550	195
14,000	16,000	900	405	280	90	110,000	120,000	1,855	790	555	205
16,000	18,000	940	420	285	94	120,000	130,000	1,875	810	560	215
18,000	20,000	975	435	290	98	130,000	140,000	1,890	835	565	225
20,000	25,000	1,055	470	315	105	140,000	150,000	1,900	850	570	235
25,000	30,000	1,130	500	340	112	150,000	160,000	1,935	870	580	245
30,000	35,000	1,205	525	360	119	160,000	170,000	1,965	890	590	255
35,000	40,000	1,275	550	380	124	170,000	180,000	1,990	905	600	265
40,000	45,000	1,340	570	400	129	180,000	190,000	2,010	920	605	275
45,000	50,000	1,400	590	420	135	190,000	200,000	2,030	935	610	285
50,000	55,000	1,460	610	440	140	200,000	210,000	2,055	955	620	295
55,000	60,000	1,515	630	455	145	210,000	230,000	2,100	980	635	315
60,000	65,000	1,565	645	470	150	230,000	250,000	2,155	1,010	650	335
65,000	70,000	1,610	660	485	155	250,000	275,000	2,215	1,040	670	360
70,000	75,000	1,655	675	500	160	275,000	300,000	2,275	1,075	690	385

are accustomed to assemble, except any building or structure occupied in connection with the manufacture, transportation, storage, or use of explosives.

NOTE 8—"Railway" means any steam, electric, or other railroad or railway which carries passengers for hire.

NOTE 9—"Highway" means any public street or public road.

NOTE 10—When two or more storage magazines are located on the same property, each magazine must comply with the minimum distances specified from inhabited buildings, railways, and highways, and in addition they should be separated from each other by not less than the distances shown for "Separation of Magazines," except that the quantity of explosives contained in cap magazines shall govern in regard to the spacing of said cap magazines from magazines containing other explosives. If any two or more magazines are separated from each other by less than the specified "Separation of Magazines" distances, then such two or more magazines, as a group, must be considered as one magazine, and the total quantity of explosives stored in such group must be treated as if stored in a single magazine located on the site of any magazine of the group, and must comply with the minimum distances specified from other magazines, inhabited buildings, railways, and highways.

NOTE 11—The Institute of Makers of Explosives does not approve the permanent storage of more than 300,000 pounds of commercial explosives in one magazine or in a group of magazines which is considered as one magazine.

NOTE 12—This Table applies only to the manufacture and permanent storage of commercial explosives. It is not applicable to transportation of explosives, or any handling or temporary storage necessary or incident thereto. It is not intended to apply to bombs, projectiles, or other heavily encased explosives.

Courtesy of The Institute of Makers of Explosives

Table of distances for explosives storage (continued)

The 1954 U.S. income tax regulations specify three ways in which depreciation may be figured on machinery and other capital assets.

The basic method, which has been standard in this country for many years, is known as straight line. The cost of the machine or other property is divided by the number of years it is expected to be useful. The resulting figure is the annual depreciation, which is deductible as a business expense.

The taxpayer has the option of dividing the whole cost into his annual depreciation figures, or subtracting a sale or salvage valúe first. For example, a machine that costs $12,960 and has an estimated life of six years may be depreciated at $2160 a year, and finish with zero value, or it may be assumed to have a salvage value (scrap or resale) of $960, and depreciation taken at $2000 a year.

If a fully depreciated machine with zero value is sold, the price obtained is business income. If sold while it still has book value, the difference between that value and the price will be profit or loss.

It is standard practice to figure excavation machinery at zero salvage value, partly because its value is difficult to predict, and partly because it is so often sold long before it is fully depreciated.

Standard depreciation rates for many machines will be found in Bulletin F, which may be obtained for 30¢ a copy from the Superintendent of Documents, Washington 25, D.C. Considerable latitude is allowed taxpayers in estimating the useful life of their machines according to their experience and bookkeeping practice. As a rule a longer period with smaller annual deductions can be substituted for standard procedure with little or no explanation, but a shorter period and higher rate is allowed only for good reason.

Two additional methods of figuring depreciation are authorized in the 1954 tax law, both of which agree with the facts by placing most of the depreciation at the beginning of use. These can be applied only to machines bought new in 1953 or later.

"Declining balance method" is based on the total cost of the machine, without allowance for salvage value. The maximum depreciation rate is twice that allowed by the straight line method, but is applied only to the value at the beginning of the year, which is the total cost the first year, and the total cost less depreciation to date for other years.

For example, a $20,000 shovel with a five year useful life would depreciate 20% or $4000 each year under the straight line method. With declining balance, depreciation the first year would be 40% of $20,000, or $8000; the second year 40% of $12,000, or $4800; the third year 40% of $7200, or $2880. At the end of the fifth year a salvage value of $1555.20 would remain.

If the shovel's life expectancy were eight years, the depreciation each year would be 25% of the value at the beginning of the year.

"Sum of the years-digits method" is based on cost less estimated salvage value. The number of years in its useful life is taken as the first figure in a descending series, which for a five year period would be 5,4,3,2,1, and for eight years 8,7,6,5,4, 3,2,1. The series is added together, giving 15 for the five year period, or 36 for eight years. A fraction is made of the number of years (numerator) over the total obtained by adding all the numbers in the series together (denominator).

First year depreciation will be this fraction 5/15 or 8/36, times the cost basis. On the $20,000 shovel, it would be $6666.67

or $4444.44. The second year depreciation is found by subtracting one from the numerator of the original fraction, and multiplying the result (4/15 or 7/36) by the first cost. On the five year period the successive deductions would be 5/15, 4/15, 3/15, 2/15, and 1/15, totalling 15/15.

The amounts allowed for salvage value should be reasonable, but they can be adjusted to simplify arithmetic. For example, if a machine with a five year life cost of $16,146.93 might be expected to bring $1,000 salvage; the salvage value could be taken as $1,146.93, leaving an even $15,000 to depreciate. In the sum of the years-digits method, depreciation would then be all in even thousands.

The taxpayer has the right to use the three methods on different machines at the same time. It is permissible to change from declining balance to straight line at any time, but other changes in method on a particular machine must be approved by tax officials.

Special methods of computing depreciation may be approved, as long as they do not allow depreciation during the first two-thirds of the equipment life than would be obtained by use of the declining balance method.

GLOSSARY

GLOSSARY

Abrasion. Wear by rubbing of coarse, hard, or sharp materials.

Abutment. The part of a bridge that supports the end of the span, and prevents the bank from sliding under it.

A foundation that carries gravity and also thrust loads.

Acre. Unit for measuring land, equal to 43,560 sq. ft.; or 4840 sq. yds.; or 160 sq. rds.

Adhesion. The soil quality of sticking to buckets, blades, and other parts of excavators.

After Cooler. Any device which will cool compressed air after it is fully compressed.

A-frame. An open structure tapering from a wide base to a load-bearing top.

Aggregate. Crushed rock or gravel screened to sizes for use in road surfaces, concrete, or bituminous mixes.

Air Receiver. The air storage tank on a compressor.

Air Waves. Air borne vibrations caused by explosions.

Alloy Steel. Steel compounded with other metals to improve its quality.

Ampere. The intensity of electric current produced by one volt acting through a resistance of one ohm.

Angle. The difference in direction of two lines which meet or tend to meet. Usually measured in degrees.

Angling Dozer (Angle dozer). A bulldozer with a blade which can be pivoted on a vertical center pin, so as to cast its load to either side.

Annular. Ring-shaped.

Anvil Block. In a paving breaker, a movable piece of steel between the air piston stem and the steel.

A.P.I. American Petroleum Institute.

A tapered thread used in drill strings and accessories.

Apron. The front gate of a scraper body.

A short ramp with a slight pitch.

Assembly Rod. An external bolt holding a machine together.

Atmospheric Pressure. Pressure of air enveloping the earth, averaged as 14.7 lbs. per sq. in. at sea level, or 29.92 inches of mercury as measured by a standard barometer.

Auger. A rotating drill having a screw thread that carries cuttings away from the face.

Auxiliary. A helper or standby engine or unit.

Avalanche Protector. Guard plates that prevent loose material from sliding into contact with the wheels or tracks of a digging machine.

Axis. A straight line around which a shaft or body revolves.

The centerline of a tunnel.

Axle, dead. A fixed shaft functioning as a hinge pin.

A fixed shaft or beam on which a wheel revolves.

Axle, live. A revolving horizontal shaft.

Babbitt. A soft antifriction metal composed of tin, antimony, and copper in varying proportions.

Backfurrow (Land). The first cut of a plow, from which the slice is laid on undisturbed soil.

Back Haul. A line which pulls a drag scraper bucket backward from the dump point to the digging.

Backfill. The material used in refilling a ditch or other excavation, or the process of such refilling.

Backfire. A fire started to burn against and cut off a spreading fire.

An explosion in the intake or exhaust passages of an engine.

Backhoe. A hoe or pull shovel.

Bail. A hinged loop used for lifting.

A hoist yoke or bracket.

Bailer. A hollow cylinder used for removing rock chips and water from churn drill holes.

Ballast. Heavy material, such as water, sand or iron, which has no function in a machine except increase of weight.

Ball Joint. A connection, consisting of a ball and socket, which will allow a limited hinge movement in any direction.

Bank. Specifically, a mass of soil rising above a digging or trucking level. Generally, any soil which is to be dug from its natural position.

Bank Gravel. A natural mixture of cobbles, gravel, sand, and fines.

Bank Measure. Volume of soil or rock in its original place in the ground.

Bank Yards. Yards of soil or rock measured in its original position, before digging.

Barrel. The water passage in a culvert.

Base Line (Traversing). The main traverse or surveyed line running through the site of proposed construction, from which property lines, street lines, buildings, etc., are located and plotted on the plan.

Batter. Inward slope from bottom to top of the face of a wall.

A pile driven at an angle to widen the area of support and to resist thrust.

Batter Boards. Horizontal boards placed to mark line and grade of a proposed building.

Battery. A storage battery or dry cell.

In blasting, often a blasting machine.

Bearing. A part in which a shaft or pivot revolves.

Bearing, anti-friction. A bearing consisting of an inner and outer ring, separated by balls or rollers held in position by a cage.

Bearing, needle. An anti-friction bearing using very small diameter rollers between wide faces.

Bearing, pilot. A small bearing that keeps the end of a shaft in line.

Bearing, solid. A one piece bushing.

Bearing, throwout. A bearing that permits a clutch throwout collar to slide along the clutch shaft without rotating with it.

Bed. A base for machinery.

Bedding. Ground or supports in which pipe is laid.

Bedding Plane. A separation or weakness between two layers of rock, caused by changes during the building up of the rock-forming material.

Bedrock. Solid rock, as distinguished from boulders.

Bell. An expanded part at one end of a pipe section, into which the next pipe fits.

Bell Crank. A lever whose two arms form an angle at the fulcrum, or a triangular plate hinged at one corner.

Belt Conveyor. An endless pulley-driven belt supported on rollers, which transports material placed on its upper surface.

Bench. A working level or step in a cut which is made in several layers.

Bench Mark. A point of known or assumed elevation used as a reference in determining and recording other elevations.

Bench Terrace. A more or less level step between steep risers, graded into a hillside.

Bends (Caisson disease). A cramping disease induced by too rapid decrease of air pressure after a stay in compressed atmosphere, as in a caisson.

Bent (Set). In tunnel timbering, two posts and a roof timber.

Berm. An artificial ridge of earth.

Bid. To make a price on anything; a proposition either verbal or written, for doing work and for supplying materials and/or equipment.

Binder. Fines which hold gravel together when it is dry.

A deposit check that makes a contract valid.

Bit. The part of a drill which cuts the rock or soil.

Bit, carbide. A bit having inserts of tungsten carbide.

Bit, chopping. A bit that is worked by raising and dropping.

Bit, coring. A bit that grinds the outside ring of the hole, leaving an inner core intact for sampling.

Bit, diamond. A rotary bit having diamonds set in its cutting surfaces.

Bit, drag. A diamond or fishtail bit.

A bit that cuts by rotation of fixed cutting edges or points.

Bit, fishtail. A rotary bit having cutting edges or knives.

Bit, multi-use. A bit that is sharpened for new service when worn.

Bit, plug. A diamond bit that grinds out the full width of the hole.

Bit, roller. A bit that contains cutting elements that are rotated inside it as it turns.

Bit, throwaway. A bit that is discarded when worn.

Bituminous. Containing asphalt or tar.

Black Powder. Gunpowder. A mixture of carbon, sodium or potassium nitrate, and sulphur.

Blade. Usually a part of an excavator which digs and pushes dirt but does not carry it.

Blanket. Soil or broken rock left or placed over a blast to confine or direct throw of fragments.

Blast. To loosen or move rock or dirt by means of explosives or an explosion.

Blast Hole. A vertical drill hole 4 or more inches in diameter, used for a charge of explosives.

Blasting Gelatin. A jelly-like high explosive made by dissolving nitrocotton in nitroglycerin.

Blasting Machine (Battery). A hand operated generator used to supply firing current to blasting circuits.

Blasting Mat. A steel blanket composed of woven cable or interlocked rings.

Bleed. To remove unwanted air or fluid from passages.

Blinding. Compacting soil immediately over a tile drain to reduce its tendency to move into the tile.

Clogging of a screen.

Block. A pulley and its case.

Block, crown. A sheave set suspended at the top of a derrick.

Block, snatch. A sheave in a case having a pull hook or ring.

Block, sling. A frame containing two sheaves mounted on parallel axles, so that they will line up when pulled from opposite directions.

Block, traveling. A frame for a sheave or a set of sheaves that slides in a track.

Blockholing. Blasting boulders by means of drilled holes.

Blue Tops. Grade stakes whose tops indicate finish grade level.

BM. Bench mark.

Body. The load carrying part of a truck or scraper.

Body, quarry. A dump body with sloped sides.

Body, rock. A dump body with oak planking set inside a double steel floor.

Bogie (Tandem) (Tandem drive unit). A two axle driving unit in a truck. Also called tandem drive unit or a tandem.

Boom. In a revolving shovel, a beam hinged to the deck front, supported by cables.

Any heavy beam which is hinged at one end and carries a weight-lifting device at the other.

Boom, crane. A long, light boom, usually of lattice construction.

Boom, jack. A boom whose function is to support sheaves that carry lines to a working boom.

Boom, lattice. A long, light shovel boom fabricated of criss-crossed steel or aluminum angles or tubing.

Boom, live. A shovel boom which can be lifted and lowered without interrupting the digging cycle.

Booster. An auxiliary device that increases force or pressure.

Booster Pump. A pump that operates in the discharge line of another pump, either to increase pressure, or to restore pressure lost by friction in the line or by lift.

Boring. Rotary drilling.

Borrow Pit. An excavation from which material is taken to a nearby job.

Boulder. A rock which is too heavy to be lifted readily by hand.

Bowl. The bucket or body of a carrying scraper.

Sometimes the moldboard or blade of a dozer.

Box. A transmission.

A dump body.

Box Girder. A hollow steel beam with a square or rectangular cross section.

Box Thread. The female side of A.P.I. tapered thread.

Brake. A device for slowing, stopping, and holding an object.

Brake, disc. A brake which utilizes friction between fixed and rotating discs, or between discs and shoes.

Brake Drum. A rotating cylinder with a machined inner or outer surface upon which a brake band or shoe presses.

Brake, friction. A brake operating by friction between two surfaces rotating or sliding on each other.

Brake Horsepower. The horsepower output of an engine or mechanical device. Measured at the flywheel or belt, usually by some form of mechanical brake.

Brake, self energizing. A brake that is applied partly by friction between its lining and the drum.

Brake, tooth (Jaw brake). A brake used to hold a shaft by means of a tooth or teeth engaging with fixed sockets. Not used for slowing or stopping.

Braze. To solder with brass or other hard alloys.

Break. To twist open or disconnect.

A short rest period.

Breast Board. A temporary barrier to prevent the digging face from caving or flowing into a tunnel.

Breast Timber. A leaning brace from the floor of an excavation to a wall support.

Bridge. In an electric blasting cap, the wire that is heated by electric current so as to ignite the charge.

Sometimes the shunt connection between the cap wires.

Bridle Cable. An anchor cable that is at right angles to the line of pull.

Bridle Hitch. A connection between a bridle cable and a cable or sheave block.

Brinell Test. A method of determining the hardness of metal by the indentation of a standard steel ball of known hardness under a definite load.

British Imperial Gallon. A fluid gallon equal to 1.2 U.S. gallons approximately; contains 277.42 cu. in. There are 6.23 such gallons per cu. ft.

Bucket. A part of an excavator which digs, lifts and carries dirt.

Bucket Loader. Usually a chain bucket loader, sometimes a tractor loader or shovel dozer.

Bucket Sheave (Padlock sheave). A pulley attached to a shovel bucket, through which the hoist or drag cable is reeved.

Bucket, slat. An openwork bucket made of bars instead of plates, used in digging sticky soil.

Bucking. Sawing a long log into shorter pieces.

Buffer. A pile of blasted rock left against or near a face to improve fragmentation and reduce scattering from the next blast.

A movable metal plate used in tunnels to limit scattering of blasted rock.

Bulkhead. A wall or partition erected to resist ground or water pressure.

Bull Clam. A bulldozer fitted with a curved bowl hinged to the top of the front of the blade.

Bull Gear. A toothed driving wheel which is the largest or strongest in the mechanism.

Bull wheel. A large driving wheel or sprocket.

Bulldozer. A tractor equipped with a front pusher blade.

A cleaning blade that follows the wheel or ladder of a ditching machine.

In a machine shop, a horizontal press.

Bullgrader. Trade name for an International (formerly Bucyrus-Erie) angling dozer.

Bumboat. A small boat equipped with a hoist and used for handling dredge lines and anchors.

Bumper (Guard). A slotted or perforated

plate that holds a check type air valve near its seat.

Burden. The distance from a drill hole to the face, or the volume of rock to be moved by the explosive in a drill hole.

Burn. To cut with a torch.

To pulverize with very heavy explosive charges.

Burn Cut. A narrow section of rock pulverized by exploding heavy charges in parallel holes.

Bushing. A metal cylinder between a shaft and a support or a wheel, that serves to reduce rotating friction and to protect the parts.

Bushing, split. A bushing made in two pieces, for ease of insertion and removal.

Butt Joint (Open joint). In pipe, flat ends that meet but do not overlap.

Cab Guard. On a dump truck, a heavy metal shield extending up from the front wall of the body and forward over the cab.

Cable. Rope made of steel wire.

Cable, backhaul. In a cable excavator, the line that pulls the bucket from the dumping point back to the digging.

Cable Control Unit. A high speed tractor winch having one to three drums under separate control. Used to operate dozers and towed equipment.

Cable, drag. In a dragline or hoe, the line that pulls the bucket toward the shovel.

Cable Excavator. A long range, cable-operated machine which works between a head mast and an anchor.

Cable, inhaul (Digging line). In a cable excavator, the line that pulls the bucket to dig and bring in soil.

Cage. A circular frame that limits the motion of balls or rollers in a bearing.

Cairn. A pile of stones used as a marker.

Caisson. A box or chamber used in contruction work under water.

Cam. A rotating or sliding piece, or a projection on a wheel, used to impart exactly timed motion to light parts.

Camber. Vertical convex curve in a culvert barrel.

Outward lean of the front wheels of a motor vehicle.

Cantilever. A lever-type beam that is held down at one end, supported near the middle, and supports a load on the other end.

Cap. A detonator, set off by electric current or a burning fuse.

A fitted or threaded piece to protect the top of a pile from damage while being driven.

A pipe plug with female threads.

The roof or top piece in a three piece timber set used for tunnel support.

Cap, delay. An electric blasting cap that explodes at a set interval after current goes through it.

Cap, millisecond delay (Short delay). A detonating cap that fires from 20 to 500 thousandths of a second after the firing current passes through it.

Capillary Attraction. The tendency of water to move into fine spaces, as between soil particles, regardless of gravity.

Capillary Movement. Movement of underground water in response to capillary attraction.

Capillary Water. Underground water held above the water table by capillary attraction.

Capstan (Cat head). A non-winding winch used with soft rope.

Carbide. Tungsten carbide, a very hard and abrasion-resistant compound used in drill bits and other tools.

Carbide Bit. A steel bit which contains inserts of tungsten carbide.

Carbon Steel. Usually a hardened steel not alloyed with other metals.

Carriage. A sliding or rolling base or supporting frame.

Carrier. A rotating or sliding mounting or case.

Carryall. Trade name for Le Tourneau-Westinghouse scrapers.

Cartridge. A wrapped stick of dynamite or other explosive.

Casing. A pipe lining for a drilled hole.

Casing Spider. A frame and wedge set that supports the top of a casing string while new sections are added.

Caster. A wheel mounted in a swivel frame so that it is steered automatically by movements of its load.

In an automotive vehicle, the toe-in of the front wheels.

Cat. A trade marked designation for any machine made by the Caterpillar Tractor Company. Widely used to indicate a crawler tractor or mounting of any make.

Cat Head. A capstan winch.

Catskinner. Operator of a crawler tractor.

Catwalk. A pathway, usually of wood or metal, that gives access to parts of large machines.

Cave (Caving). Collapse of an unstable bank.

Center of Gravity. That point in a body about which all the weights of all the various parts balance. It is found experimentally by balancing on a knife edge or a point.

The center of mass of a cut or a fill.

Center of Mass. In a cut or a fill, a cross section line that divides its bulk into halves.

Centerpin (Center pintle). In a revolving shovel, a fixed vertical shaft around which the shovel deck turns.

Centigrade. A temperature scale on which the freezing point of water at sea level atmospheric pressure is indicated as 0° and its boiling point as 100°. Degrees centigrade (°C) equals Fahrenheit (°F) minus 32 multiplied by $\frac{5}{9}$.

Centralizer. A device that lines up a drill steel or string between the mast and the hole.

Centrifugal Force. Outward force exerted by a body moving in a curved line. It is the force which tends to tip a car over in going around a curve.

Centripetal Force. The force or restriction exerted inward to keep a body moving in a curved line. The force which keeps a car from being thrown out of a curve about which it is moving is centripetal force.

Cetane Number. An indication of diesel fuel ignition quality. The cetane number of a fuel in the percentage by volume of cetane in a mixture of cetane and alpha-methylnapthlalene which matches the unknown fuel in ignition quality. American diesel oil usually varies from 30 to 60 cetane.

c.f.m. Cubic feet per minute. A standard capacity or performance measurement for compressors.

C-frame. An angling dozer lift and push frame.

Chain. A tow line or drive belt made of interlocked links.

A surveyor's steel tape measure.

Chain, breakaway (Safety chain). A chain that holds a tractor and a towed unit together if the regular fastening opens or breaks.

Chain Bucket Loader (Bucket loader). A mobile loader that uses a series of small buckets on a roller chain to elevate spoil to the dumping point.

Chain, leaf. A silent chain designed for low speed heavy duty work.

Chain, logging. A chain composed of links of round bar bieces curved and welded to interlock, with a grab hook at one end and a round hook at the other.

Chain, roller. Generally, any sprocket-driven chain made up of links connected by hinge pins and sleeves.

Specifically, a chain whose hinge sleeves are protected by an outer sleeve or roller that is free to turn.

Chain, silent. A roller-type chain in which the sprockets are engaged by projections on the link side bars.

Chain, stud type. A roller chain in which the inner (block) links are connected solidly by non-rotating bushings.

Chanfer (Chamfer). To bevel or slope an edge or corner.

Channel Terrace. A contour ridge built of soil moved from its uphill side, which serves to divert surface water from a field.

Check Dam. A dam that divides a drainageway into two sections with reduced slopes.

Check Valve. Any device which will allow fluid or air to pass through it in only one direction.

Cherry Picker. A small derrick made up of a sheave on an A-frame, a winch and winch line, and a hook. Usually mounted on a truck.

Chip Blasting. Shallow blasting of ledge rock.

Chipping. Loosening of shallow rock by light blasting or air hammers.

Chock. A block used under and against an object to prevent it from rolling or sliding.

Choker. A chain or cable so fastened that it tightens on its load as it is pulled.

Choker Hook (Round hook). A hook that can slide along a chain.

Chord. A straight line connecting two points on a curve.

Chuck. The part of a drill that rotates the steel.

A device that clamps a rod or shaft.

Churn Drill (Spudding or well drill). A machine that drills holes by dropping and raising a bit and drill string hung by a cable.

Circle. In a grader, the rotary table which supports the blade and regulates its angle.

Circle Reverse. The mechanism that changes the angle of a grader blade.

Clam. A clamshell bucket.

Clamshell. A shovel bucket with two jaws which clamp together by their own weight when it is lifted by the closing line.

A shovel equipped with a clamshell bucket.

Clay. A "heavy" soil composed of particles less than 1/256 mm in diameter.

Clean. Free of foreign material. In reference to sand or gravel, means lack of binder.

Cleavage Plane. Any uniform joint, crack, or change in quality of formation along which rock will break easily when dug or blasted.

Clevis. A shackle.

A split end of a rod, drilled for insertion of a pin through the two sections.

Clinometer. A hand instrument for measuring grades by sighting.

Clod Buster. A drag that follows a grading machine to break up lumps.

Closing Line (Digging line). The cable which closes the jaws of a clamshell bucket.

Cloth, wire. Screen composed of wire or rod woven and crimped into a square or rectangular pattern.

Clutch. A device which connects and disconnects two shafts which revolve in line with each other.

Clutch, automatic. A clutch whose engagement is controlled by centrifugal force, vacuum, or other power without attention by the operator.

Clutch Brake. A device to slow the jackshaft when a clutch is released, to permit more rapid gear shifting.

Clutch, centrifugal. A clutch that is kept in engagement only by centrifugal force, so that it automatically disconnects the power train when the engine idles.

Clutch, denture. A jaw clutch.

Clutch, disc. A coupling that can be engaged to transmit power through one or more discs squeezed between a back-plate and a movable

pressure plate, and that can be disengaged by moving the plates apart.

Clutch, fluid. A fluid coupling other than a torque converter.

Clutch, jaw (Positive or denture clutch). A toothed hub and a sliding toothed collar that can be engaged to transmit power between two shafts having the same axis of revolution.

Clutch, lockup. A clutch that can be engaged to provide a non-slip mechanical drive through a fluid coupling.

Clutch, overrunning (Free wheeling unit). A coupling that transmits rotation in only one direction, and disconnects when the torque is reversed.

Clutch, slip (Safety clutch). A friction clutch that protects a mechanism by slipping under excessive load.

Clutch, wet (Oil clutch). A clutch that operates in an oil bath.

Cobble. Rounded stone with diameter of 4 to 12 inches.

Cocking. Tipping sideward.

Running off center.

Cockpit. The part of a tractor or grader containing the operator's seat and controls.

Cocoa Mat. A fabric of wood fibers used to distribute water evenly over a smooth surface.

Cofferdam. A set of temporary walls designed to keep soil and/or water from entering an excavation.

Cohesion. The soil quality of sticking together.

Conduit. A pipe or tile carrying water, wire, or pipes.

Collar. A sliding ring mounted on a shaft so that it does not revolve with it. Used in clutches and transmissions.

The open end of a drill hole.

Collaring. Starting a drill hole. When the hole is deep enough to hold the bit from slipping out of it, it is said to be collared.

Compaction. Reduction in bulk of fill by rolling, tamping or soaking.

Compacted Yards. Measurement of soil or rock after it has been placed and compacted in a fill.

Compensating Drive. In a four wheel drive truck, a free wheeling unit in the front propeller shaft that allows the front wheels to go farther than the rear on curves.

Compression. For steel wheel rollers, the compacting effect of the weight at the bottom of the roll, measured in pounds per linear inch of roll width.

Compression Ratio. The ratio of the volume of space above a piston at the bottom of its stroke to the volume above the piston at the top of its stroke.

Compression Roll (Drive roll). The drive wheel of a steel wheel roller.

Compressor. A machine which compresses air.

Concussion. Shock or sharp air waves caused by an explosion or heavy blow.

Cone of Depression. The dried up area of soil around a single underground suction point.

Contour Line. A level line crossing a slope.

Conveyor. A device that transports material by belts, cables, or chains.

Conveyor, apron. One or more endless chains carrying overlapping or interlocking plates that carry bulk materials on their upper surface.

Conveyor Belt. An endless belt of rubber-covered fabric that transports material on its upper surface.

Conveyor, decline. A conveyor that transports downhill.

Conveyor, feeder. A short conveyor belt that supplies material to a long belt.

Conveyor, screw. A revolving shaft fitted with auger-type flights that moves bulk materials through a trough or tube.

Corduroy. A road made of logs laid crosswise on the ground or on other logs.

Cordwood. Wood cut in 4-foot or shorter lengths to be used as fuel.

Core. A cylindrical piece of an underground formation cut and raised by a rotary drill with a hollow bit.

Core Barrel. A hollow cylinder containing a socket and choker springs for holding a section of drilled rock.

Core Drill. A rotary drill, usually a diamond drill, equipped with a hollow bit and a core lifter.

Corrosion. Wear or dissolving away through chemical action as by rusting, or acids.

Countershaft. A shaft which receives power from a parallel mainshaft, and transmits it to another part of the mainshaft or to working parts.

Counterweight. A "dead" or non working load attached to one end or side of a machine to balance weight carried on the opposite end.

A working part attached or positioned partly for the purpose of improving machine balance.

Coyote Holes. Horizontal tunnels in which explosives are packed for blasting a high rock face.

Cradle. A support bracket with a hinged connection to its load.

A carriage.

Crane. A mobile machine used for lifting and moving loads without use of a bucket.

Crankshaft. The engine shaft that converts the reciprocating motion and force of pistons and connecting rods to rotary motion and torque.

Crawler. One of a pair of roller chain tracks used to support and propel a machine, or any machine mounted on such tracks.

Creep. Very slow travel of a machine or a part.

Unwanted turning of a shaft due to drag in a fluid coupling or other disconnect device.

Crimp. A tight bend in metal made under pressure.

Cross Hair. A hair mounted horizontally in a

telescope so as to divide the field of view into halves.

Crosshead. A connection between a connecting rod and a piston rod which is guided so as to move in a straight line.

Cross Section. A profile taken at right angles to the centerline of a project.

Cross Section Paper. Paper ruled in squares for convenience in drawing and measuring.

Crowd. The process of forcing a bucket into the digging, or the mechanism which does the forcing. Used chiefly in reference to machines which dig by pushing away from themselves.

Crown. The elevation of a road center above its sides.

The curved roof of a tunnel.

Crown Fire. A fire burning in tree tops.

Crumber. A "bulldozer" blade that follows the wheel or ladder of a ditching machine to clean and shape the bottom.

Crusher. A machine which reduces rocks to smaller and more uniform sizes. *See also Jaw, Gyratory, and Hammer Mill.*

Culvert. A pipe or small bridge for drainage under a road or structure.

Curtain Drain (Intercepting drain). A drain that is placed between the water source and the area to be protected.

Curve, vertical. A change in gradient of the center line of a road or pipe.

Cut. To lower an existing grade.

An artificial depression.

To stop an engine, or throttle it to idling speed.

Cut and Cover. A work method which involves excavation in the open, and placing of a temporary roof over it to carry traffic during further work.

Cut, gross. The total amount of excavation in a road or a road section, without regard to fill requirements.

Cut, net. The amount of excavated material to be removed from a road section, after completing fills in that section.

Cutter (Cutter head). On a hydraulic dredge, a set of revolving blades at the end of the suction line.

Cutting. Excavating.

Lowering a grade.

Cycle, digging. Complete set of operations a machine performs before repeating them.

Cylinder. In hydraulic systems, a hollow cylinder of metal, containing a piston, piston rod and end seals, and fitted with a port or ports to allow entrance and exit of fluid.

Cylinder, slave. A small cylinder whose piston is moved by a piston rod controlled by a larger cylinder.

Dart Valve. A drain for a well bailer that opens automatically when rested on the ground.

Datum. Any level surface taken as a plane of reference from which to measure elevations.

Dead Axle. See Axle, dead.

Dead Furrow. The line in a field where two directions of plowing meet, and the slices are turned away from each other.

Deadheading. Traveling without load, except from the dumping area to the loading point.

Deck Screens. Two or more screens, usually of the vibrating type, placed one above the other.

Decking. Separating charges of explosives by inert material which prevents passing of concussion, and placing a primer in each charge.

Decompression. The process of reducing high air pressure gradually enough not to injure men who have been working in it.

Deflagration. To burn with sudden and startling combustion. Describes explosion of black powder, in contrast with more rapid detonation of dynamite.

Degree of Curve. The number of degrees at the center of a circle subtended by a chord of 100 ft. at its rim. Occasionally in highway surveying it is defined as the central angle subtended by an arc of 100 feet.

Delay. An electric blasting cap which explodes at a set interval after current is passed through it.

Delay, short period (Millisecond delay). An electric blasting cap that explodes 1/50 to ½ second after passage of an electric current.

Density. The ratio of the weight of a substance to its volume.

Derrick. Usually a non-mobile tower equipped with a hoist, but may be used as a synonym for crane.

Detail Drawing. A large scale drawing showing all small parts, details, dimensions, etc.

Detergent. A chemical compound that acts to clean surfaces and to keep foreign matter in solution or suspension.

Detonation. Practically instantaneous decomposition or combustion of an unstable compound, with tremendous increase in volume.

Detonator. A device to start an explosion, as a fuse or cap.

Dewatering. Removing water by pumping, drainage, or evaporation.

Diamond Drill. A light rotary drill, most often used for exploratory work and blast holes.

Diaphragm. A flexible partition between two chambers.

Dieseling. In a compressor, explosions of mixtures of air and lubricating oil in the compression chambers or other parts of the air system.

Differential. A device that drives two axles and allows them to turn at different speeds to adjust to varying resistance.

Differential, non-spin (Limited action differential). A differential that will turn both axles, even if one offers no resistance.

Differential, two speed. A differential having

a high-low gearshift between the drive shaft and the ring gear.

Diffuser. Inner shell and water passages of a centrifugal pump.

Digging Line. On a shovel, the cable which forces the bucket into the soil. Called crowd in a dipper shovel, drag in a pull shovel and dragline and closing line in a clamshell.

Dike. A long low dam.

A thin rock formation that cuts across the structure of surrounding rock.

Dimension Stone. Rock quarried in blocks to predetermined sizes, in such a manner as not to weaken or shatter it.

Dip. The slope of layers of soil or rock.

Dipper. A digging bucket rigidly attached to a stick or arm.

Dipper Stick. A name for the standard revolving shovel (dipper shovel), and for the straight shaft which connects the bucket with the boom.

Dipper Trip. A device that unlatches the door of a shovel bucket to dump the load.

Direction of Irrigation. Direction of flow of irrigation water. Usually at right angles to the supply ditch or pipe.

Ditch. Generally, a long narrow excavation.

In rotary drilling, a trough carrying mud to a screen.

Ditcher, ladder. A machine that digs trenches by means of buckets mounted on a pair of chains traveling on the exterior of a boom.

Ditcher, wheel. A machine that digs trenches by rotation of a wheel fitted with toothed buckets.

Diversion Valve. A valve which permits flow to be directed into any one of two or more pipes.

Dog. A heavy duty latch.

Dolly. A unit consisting of draw tongue, an axle with wheels, and a turntable platform to support a trailer gooseneck.

A small wheeled carriage designed to support heavy machines.

Donkey. A winch with two drums which are controlled separately by clutches and brakes.

Dope. A viscous liquid put on pipe threads to make a tight joint.

Double. In rotary drilling, two pieces of drill rod left fastened together during raising and lowering.

Double-Clutching. Disengaging and engaging the clutch twice during a single gear shift, in order to synchronize gear speeds.

Downstream Face. The dry side of a dam.

Dozer. Abbreviation for bulldozer or shovel dozer.

Dozer Shovel (Shovel dozer). A tractor equipped with a front-mounted bucket that can be used for pushing, digging, and truck loading.

Draft. Resistance to movement of a towed load.

Drag. Pulling a bucket into the digging, or the mechanism by which the pulling is done or controlled.

Drag Brake. On a revolving shovel, the brake which stops and holds the drag (digging) drum.

Drag Scraper. A digging and transporting device consisting of a bottomless bucket working between a mast and an anchor.

A towed bottomless scraper used for land leveling. Called "leveling drag scraper" to distinguish from cable type.

Dragline. A revolving shovel which carries a bucket attached only by cables, and digs by pulling the bucket toward itself.

Dragshovel (Hoe, Backhoe, or Pullshovel). A shovel equipped with a jack boom, a live boom, a hinged stick and a rigidly attached bucket, that digs by pulling toward itself.

Drain, intercepting (Curtain drain). A drain that intercepts and diverts ground water before it reaches the area to be protected.

Drainage Head. The furthest or highest spot in a drainage area.

Draw. A small valley or a gully.

Drawbar. In a tractor, a fixed or hinged bar extending to the rear, used as a fastening for lines and towed machines or loads.

In a grader, the connection between the circle and the front of the frame.

Drawbar Horsepower. A tractor's flywheel horsepower minus friction and slippage losses in the drive mechanism and the tracks or tires.

Drawbar Pull. The pull a tractor can exert on a load attached to the drawbar. Depends on power, weight, and traction.

Draw Knife. A curved, two handled knife used in digging clay.

Draw Pin. A removable pin that attaches a load to a drawbar.

Drawpoint. A spot where gravity fed ore from a higher level is loaded into hauling units.

Draw Tongue. A bar hinged to a towed machine, fitted with some device for attaching it to a tractor.

Draw Works. The power distribution and control machinery of a rotary drill.

Dredge. To dig under water.

A machine that digs under water.

Drift. A small nearly horizontal tunnel.

Drifter. An air drill mounted on a column or cross bar, and used for horizontal drilling underground.

Drill, auger. See Auger.

Drill Bit. See Bit.

Drill, blast hole. A machine capable of drilling holes 4 inches or more in diameter to a depth of 100 or more feet.

Drill, churn (Spudding drill). A drill that cuts its hole by raising and dropping a chisel bit.

Drill Collar. Thick walled drill pipe used immediately above a rotary bit to provide extra weight.

Drill, core. A drill that cuts around a cylinder

of rock or soil, and lifts it to the surface for inspection.

Drill, diamond. A rotary drill that uses a diamond-studded bit.

Drill Doctor. A mechanic or shop that sharpens and services drill bits, tools and steels.

Drill, percussion. A drill that hammers and rotates a steel and bit.

Sometimes limited to large blast hole drills of the percussion type.

Drill Pipe. The sections of a rotary drilling string connecting the kelly with the bit or collars.

Drill, quarry. A blast hole drill.

Drill Steel. Hollow steel connecting a percussion drill with the bit.

Drill String. In rotary drills, all revolving parts below the ground.

In churn drills, the tools hanging from the drilling cable.

Drill, well. A churn drill, mounted on a truck.

Drilling, core. Exploratory drilling that includes cutting cylinders of rock or soil and bringing them to the surface for inspection.

Drilling, directional (Offset drilling). Curving a rotary drill hole to avoid obstacles or to reach side areas.

Drilling, solid. In diamond drilling, using a bit that grinds the whole face, without preserving a core for sampling.

Drive. To dig or make a tunnel.

To hammer down piling.

Drive Clamp. A collar fitted on a churn drill string to enable it to be used as a hammer to drive casing pipe.

Drive, positive. A driving connection to two or more wheels or shafts that will turn them at approximately the same relative speeds under any conditions.

Drop Hammer. A pile driving hammer that is lifted by a cable and that obtains striking power by falling freely.

Drum. A rotating cylinder with side flanges, used for winding in and releasing cable.

Drum, spudding. In a churn drill, the winch that controls the drilling line.

Dry Well. A deep hole, covered, and usually lined or filled with rocks, that holds drainage water until it soaks into the ground.

Dynamic. Forces tending to produce motion.

Dynamic Balance. A condition of rest created by equal strength of forces tending to move in opposite directions.

Dynamite. A mixture of an explosive or explosives with relatively inert material.

Dynamite, straight. A dynamite in which nitroglycerin is the principal or only explosive.

Earth Drill. An auger.

Eccentric. A wheel or cam with an off-center axis of revolution.

Ejector. A cleanout device, usually a sliding plate.

Elevating Grader. See Belt Loader.

Elevation (Surveying). The height of a point above a plane of reference.

Elevator. A cage hoist.

A machine that raises material on a belt or a chain of small buckets.

Embankment. A fill whose top is higher than the adjoining surface.

Erosion. Wear caused by moving water or wind.

Excavation, unclassified. Excavation paid for at a fixed price per yard, regardless of whether it is earth or rock.

Exploit. Excavate in such a manner as to utilize material in a particular vein or layer, and waste or avoid surrounding material.

Explosive. A chemical compound that can decompose quickly and violently.

Explosive, high. A material that detonates, that is, explodes almost instantaneously.

Face. The more or less vertical surface of rock exposed by blasting or excavating, or the cutting end of a drill hole.

An edge of rock used as a starting point in figuring drilling and blasting.

The width of a roll crusher.

Factor of Safety. The ratio of the ultimate strength of the material to the allowable or working stress.

Fairlead. A device which lines up cable so that it will wind smoothly onto a drum.

False Set (Horsehead). A temporary support for forepoles used in driving a tunnel in soft ground.

Fast Powder. Dynamites or other explosives having a high speed detonation.

Faulting. In geology, the movement which produces relative displacement along a fracture in rock.

Feather. To blend the edge of new material smoothly into the old surface.

Feed. A mechanism which pushes a drill into its work.

The process of supplying material to a conveying or processing unit.

Feeder. A pushing device or short belt that supplies material to a crusher or a conveyor.

Feed Travel. The distance a drilling machine moves the steel shank in traveling from top to bottom of its feeding range.

Ferrule. A short unthreaded tube or bushing shrunk or soldered onto a tube or line.

Fifth Wheel. The weight-bearing swivel connection between highway-type tractors and semitrailers.

An unnecessary machine or person working on a job.

Fill. An earth or broken rock structure or embankment.

Soil or loose rock used to raise a grade.

Soil that has no value except bulk.

Fill, net. In sidehill work, the yardage of fill required at any station, less the yards of material obtained from the cut at that station.

Fill, net corrected. Net fill after making allowance for shrinkage during compaction.

Filter Bed. A fill of pervious soil that provides a site for a septic field.

Filter Cake (Mud cake). A deposit of mud on the walls of a drill hole.

Final Drive. A set of reduction gearing close to or inside of a drive wheel.

Fines. Clay or silt particles in soil.

Finish Grade. The final grade required by specifications.

Fishing. The operation of recovering an object left or dropped in a drill hole.

Fitting, poured. A wire rope attachment fastened to it by separating the wires, expanding them in a conical socket, and filling it with molten zinc.

Fitting, wedge socket. A wire rope attachment in which the rope lies in a too-small groove between a wedge and a housing, so that pull on the rope tightens the wedge.

Flail. A hammer hinged to an axle so that it can be used to break or crush material.

Flame Gun. A large blowtorch using kerosene for fuel.

Flange. A ridge that prevents a sliding motion.

A rib or rim for strength or for attachments.

Fleet Angle. The maximum angle between a rope and a line perpendicular to the drum on which it winds.

Flight. The screw thread (helix) of an auger.

Float. In reference to a dozer blade—to rest by its own weight, or to be held from digging by upward pressure of a load of dirt against its moldboard.

Flotation. Separation of minerals by floating the lighter ones in a fluid.

The weight supporting ability of a tire, crawler track, or platform on soft ground.

Flow Gradient. A drainageway slope determined by the elevation and distance of the inlet and outlet, and by required volume and velocity.

Fluid Clutch. A hydraulic coupling which does not increase torque.

Fluid Drive. A connection between two shafts that transmits torque through a fluid.

Flume. An artificial channel, often elevated above the ground, used to carry fast flowing water.

Follower. A piston that maintains a light pressure against a variable amount of fluid in a container.

Foot. In tamping rollers, one of a number of projections from a cylindrical drum.

Foot Pins. The hinge which attaches the boom to a revolving shovel.

Foot-Pound. Unit of work equal to the force in pounds multiplied by the distance in feet through which it acts. When a 1 pound force is exerted through a 1 foot distance, 1 foot pound of work is done.

Foot Valve. A check valve in the inlet end of a pump suction hose.

Footing (Foot wall). A sill under a foundation.

Ground, in relation to its load bearing and friction qualities.

Ford. A place where a road crosses a stream under water.

Forepole. A plank driven ahead of a tunnel face to support the roof or wall during excavation.

Fork. A two-pronged rod or yoke used to slide shifting collars along their shafts.

Fork Head. A wheel-guiding frame with a swivel connection to the machine or vehicle that rests on it. (A caster frame.)

Foul Air Duct. A suction line in a tunnel ventilation system.

Four by Four (4×4). A vehicle with four wheels or sets of wheels, all engine driven.

Four-Part Line. A single rope or cable reeved around pulleys so that four strands connect the fixed and the movable units.

Fourble. In rotary drilling, a unit of four drill pipes left coupled together.

French Drain (Rubble or stone drain). A covered ditch containing a layer of fitted or loose stone or other pervious material.

Friction. Resistance to motion when one body is sliding or tending to slide over another.

Front. The working attachment of a shovel, as dragline, hoe, or dipper stick.

Front End Loader. A tractor loader with a bucket which operates entirely at the front end of the tractor.

Frost. Frozen soil.

Frost Line. The greatest depth to which ground may be expected to freeze.

Fulcrum. A pivot for a lever.

Full Trailer. A towed vehicle whose weight rests entirely on its own wheels or crawlers.

Fumes. Usually smoke from an explosion.

Fumes, excellent. Fumes that contain a minimum of toxic and irritating chemicals.

Fumes, poor. Toxic or irritating chemicals produced by an explosion.

Fuse. A thin core of black powder surrounded by wrappings, which, when lit at one end, will burn to the other at a fixed speed.

Fuse, detonating. A string-like core of PETN, a high explosive, contained within a waterproof reinforced sheath. "Primacord" is the best known brand.

Gantry. An overhead structure that supports machines or operating parts.

An upward extension of a shovel revolving frame that holds the boom line sheaves.

Gauge (Gage). Thickness of wire or sheet metal.

Spacing of tracks or wheels.

Gear. A toothed wheel, cone, or bar.

Gear, bevel. A gear made of teeth cut in the surface of a truncated cone.

Gear, bull. A gear or sprocket that is much larger than the others in the same power train.

Gear, cluster. Two or more gears of different sizes made in one solid piece.

Gear, helical. A gear with straight or curved teeth cut at an angle of less than 90° to the direction of rotation.

Gear, herringbone. A gear with V-teeth.

Gear, idler. A gear meshed with two other gears that does not transmit power to its shaft. Used to reverse direction of rotation in a transmission.

Gear, pinion. A drive gear that is smaller than the gear it turns.

Gear, planetary set. A gear set consisting of an inner (sun) gear, an outer ring with internal teeth, and two or more small (planet) gears meshed with both the sun and the ring.

Gear, rack. A toothed bar.

Gear, sprocket. A gear that meshes with roller or silent chain.

Gelatin, blasting. A high explosive made by dissolving nitrocotton in nitroglycerin. It is the strongest and highest velocity commercial explosive.

General Drawing. A drawing showing elevation plan, and cross section of the structure, also the borings for substructure and the main dimensions, etc.

Giant (Monitor). In hydraulicking, a large high pressure nozzle mounted in a swivel on a skid frame.

Glory Hole. A vertical pit, material from which is fed by gravity to hauling units in a shaft under the pit bottom.

Gooseneck. An arched connection, usually between a tractor and a trailer.

Grade. Usually the elevation of a real or planned surface or structure. Also means surface slope.

Grader. A machine with a centrally located blade that can be angled to cast to either side, with independent hoist control on each side.

Grade Stake. A stake indicating the amount of cut or fill required to bring the ground to a specified level.

Gradient. Slope along a specific route, as of a road surface, channel or pipe.

Grapple. A clamshell-type bucket having three or more jaws.

Gravel. Rock fragments from 2 mm to 64 mm (.08 to 2.5 inches) in diameter. Or a mixture of such gravel with sand, cobbles, boulders, and not over 15 percent of fines.

Grease. Thick oil.

A solid or semi-solid mixture of oil with soap or other fillers.

Grid. A set of surveyor's closely spaced reference lines laid out at right angles, with elevations taken at line intersections.

Grief Stem. A kelly.

Grizzly. A coarse screen used to remove oversize pieces from earth or blasted rock.

A gate or closure on a chute. (May be spelled "grizzlie.")

Ground Pressure. The weight of a machine divided by the area in square inches of the ground directly supporting it.

Ground Waves. Vibrations of soil or rock.

Grouser. A ridge or cleat across a track shoe, which improves its grip on the ground.

Grout. A cementing or sealing mixture of cement and water, to which sand, sawdust, or other fillers may be added.

Grubbing. Digging out roots.

Guage Size. The width of a drill bit along the cutting edge.

Guard (Bumper). In a compressor check valve a backing or retaining plate for the movable part.

Gudgeon. A reinforced bushing or a thrust absorbing block.

Guy. A line that steadies a high piece or structure by pull against an off-center load or other guys.

Gypsy Spool (Cat head). A capstan winch.

Gyratory Crusher. A crusher having a central conical member with an eccentric motion in a circular chamber tapering from a wide top opening.

Half Track. A heavy truck with high speed crawler track drive in the rear and driving wheels in front.

Hammer Mill (Hammermill). A rock crusher or a shredder employing hammers or flails on a rapidly rotating axle.

Handle (Stick). In a dipper shovel or hoe, the arm that connects the bucket with the boom.

Hand Level. A sighting level that does not have a tripod, base, or telescope.

Hardpan. Hard, tight soil.

A hard layer that may form just below plow depth on cultivated land.

Harrow. An agricultural tool that loosens and works the ground surface.

Haul. Average Haul—The average distance a grading material is moved from cut to fill.

Haul Distance—Is the distance measured along the center line or most direct practical route between the center of the mass of excavation and the center of mass of the fill as finally placed. It is the distance material is moved.

Haul, station yards of—Equals the number of cubic yards multiplied by the number of 100 ft. stations through which it is moved.

Haul, free—Is the distance every cubic yard is entitled to be moved without an additional charge for haul.

Haul, over-—Is the distance in excess of that

given as the stated haul distance to haul excavated material.

Haulageway. A main tunnel connecting underground excavation areas with an exit.

Haulaway. An excavation method which involves hauling the spoil away from the hole.

Haunch. In pipe, the sides of the lower third of the circumference.

Head. Height of water above a specified point.

The back-pressure against a pump from a high outlet.

Heading. In a tunnel, a digging face and its work area.

Head Mast. In a cable excavator, the tower that carries the working lines.

Headwall (Sidewall). A culvert sidewall. Sometimes only the upstream wall.

Heap. The soil carried above the sides of a body or bucket.

Heel. A floor brace or socket for wall-bracing timbers.

The trailing edge of an angled blade.

Heeling In. Temporary planting of trees and shrubs.

Helical. Spiral.

H. I. Height of instrument.

High Line. A high tension electric line.

Electric power supplied by a utility.

High Wall. A face which is being excavated, as distinguished from spoil piles.

Undisturbed soil or rock bordering a cut.

Hinge. A connection which allows swinging motion in one plane.

Hitch. A horizontal shelf along the side of a rock tunnel, that supports roof timbers.

A connection between two machines.

Hoe (Backhoe, pullshovel). A shovel that digs by pulling a boom-and-stick-mounted bucket toward itself.

Hog Box. A concrete box in which water and dirt are mixed to be pumped to a fill.

Hoist. The mechanism by which a bucket or blade is lifted, or the process of lifting it.

Hood. A casing on the end of a suction line that causes it to pick up material from the bottom only.

A curved baffle that prevents scattering and separation of material discharged by a conveyor belt.

Hook, cable. A round hook with a wide beveled face.

Hook, grab. A chain hook that will slide over any one link, but will not slide along the chain.

Hook, pintle. A towing bracket having a fixed lower part, and a hinged upper one, which when locked together make a round opening that can hold a tow ring.

Hook, round (Slip hook). A hook that has smooth inner surface, and will slide along a chain.

Hook, safety (Lockon hook). A round hook with a hinged piece across the opening, that allows a line to enter it readily, but requires special manipulation to remove it.

Hook, swivel. A hook with a swivel connection to its base or eye.

Hopper. A storage bin or a funnel that is loaded from the top, and discharges through a door or chute in the bottom.

Horizon. A horizontal layer.

Horse. A saw horse or other simple frame or support.

Horsehead (False set). A temporary support for forepoles used in tunneling soft ground.

HP (hp). Horsepower.

Horsepower. A measurement of power that includes the factors of force and speed.

The force required to lift 33,000 pounds one foot in one minute.

Horsepower, drawbar. Horsepower available to move a tractor and its load, after deducting losses in the power train.

Horsepower, Indicated. The horsepower developed in the cylinders. Determined by use of an indicator gauge. Does not include engine friction losses.

Horsepower, rated. Theoretical horsepower of an engine based on dimensions and speed.

Power of an engine according to a particular standard.

Horsepower, shaft (Flywheel or belt horsepower). Actual horsepower produced by the engine, after deducting the drag of accessories.

Holdback. An automatic safety device that prevents a conveyor belt from running backward.

Holding Line. The hoist cable for a clamshell bucket.

Hot Mill. To heat metal, then shape it.

Housing. A heavy case or enclosure for rotating parts.

Hub. The strengthened inner part or mounting of a wheel or gear.

Hull. The substructure and deck of a ship or dredge.

Humus. Decayed organic matter.

A dark fluffy swamp soil composed chiefly of decayed vegetation, that is also called peat.

Hunting Tooth. A sprocket and roller chain combination in which one has an odd number of contacts and the other an even number, so that no tooth will contact the same pin twice in succession.

Hydraulic Dredge. A floating pump that sucks up a mixture of water and soil, and usually discharges it on land through pipes.

Hydraulic Fill. Fill moved and placed by running water.

Hydraulic Gradient. The slope of the surface of open or underground water.

Hydraulicking. Excavating on dry land by means of water jets.

Hydrometer. A device (usually a float in a glass tube) for measuring the specific gravity of fluids.

Hydrostatic. Relating to pressure or equilibrium of fluids.

Hygroscopic. Water absorbed from the atmosphere.

Hypoid. A pinion-and-ring gear set transmitting rotation through a right angle by means of teeth having structure intermediate between a bevel and a worm set.

I.C.C. Interstate Commerce Commission.

Idler. A wheel or gear which changes the direction of rotation of shafts, or the direction of movement of a chain or belt.

Impeller. A rotary pump member using centrifugal force to discharge a fluid into outlet passages.

Impervious. Resistant to movement of water.

Inclined Plane. A slope used to change the direction and speed-power ratio of a force.

Inertia. The property of matter by which it will remain at rest, or in uniform motion in a straight line, unless acted upon by an external force.

Inhaul. The line or mechanism by which a cable excavator bucket is pulled toward the dump point.

Injector. In a diesel engine, the unit that sprays fuel into the combustion chamber.

Instrument. A telescopic level, such as a transit or a builders' level.

Intercepting Drain. Curtain drain.

Intercooler. A radiator in which air is cooled while moving from low pressure to high pressure cylinders of a two stage compressor.

Intermediate Shaft. A shaft which is driven by one shaft, and drives another.

Interruptions. Secondary cutters in auger drills.

Invert. The inside bottom of a pipe or tunnel.

Jack. A mechanical or hydraulic lifting device.
A hydraulic ram or cylinder.

Jack Boom. A boom which supports sheaves between the hoist drum and the main boom in a pull shovel or a dredge.

Jack Hammer. An air drill that hammers and rotates a hollow steel and a bit, and that can be operated by one man.

Jackknife. A tractor and trailer assuming such an angle to each other that the tractor cannot move forward.

Jackleg. An outrigger post.

Jackshaft. A short drive shaft, usually connecting a clutch and transmission.

Jars. A tool in the churn drill string which contains slack to allow hammering upward to free a stuck bit.

Jaw. In a clutch, one of a pair of toothed rings, the teeth of which face each other.

In a crusher, one of a pair of nearly flat faces separated by a wedge-shaped opening.

Jaw Clutch. A clutch consisting of two toothed jaws, one of which slides along its shaft to engage or disengage from the other.

Jaw Crusher. A fixed and a movable jaw widely spaced at the top and close at the bottom, with means to move one jaw toward and away from the other.

Jetting. Drilling with high pressure water or air jets.

Jetty. A long fill or structure extending into water from the shore, that serves to change the direction or velocity of water flow.

Jib Boom. An extension piece hinged to the upper end of a crane boom.

Jig. A guide used in shaping pieces of wood or metal.

Journal. That part of a rotating shaft or axle which turns in a load-supporting bearing.

Jumbo. A number of drills mounted on a mobile carriage, and used in tunnels.

Kelly. A square or fluted pipe which is turned by a drill rotary table, while it is free to move up and down in the table. Also called grief stem.

Key. A hard steel strip inserted in matching grooves (keyways) in a shaft and a hub to make them turn as a unit.

Keyhole Slot. A slot enlarged at one end to allow entrance of a chain or bolt that can then be held by the narrow end.

Keyway. A square edged lengthwise slot in a shaft or hub.

Kill. Cut off electric current from a circuit.
Stop an engine.

Kilowatt. An electrical unit of work or power. Equal to 1000 watts, 1.34 horsepower, and 1.18 KVA.

Kingpin (King pin). A vertical swivel or hinge pin, usually supported at both top and bottom.

Knife. The dirt cutting edge of a digging machine.

KVA (Kilovolt-ampere) Approximately $^{85}\!/_{100}$ of a kilowatt.

Lacing. Small boards or patches that prevent dirt from entering an excavation through spaces between sheeting or lagging planks.

Ladder. The digging boom assembly in a hydraulic dredge or chain-and-buckets ditcher.

Ladder Ditcher. A machine that digs ditches by means of buckets in a chain that travels around a boom.

Lag. Delay in one action following another.
To install lagging, or increase the diameter of a drum.

Lagging. The surface or contact area of a drum or flat pulley, especially a detachable surface or one of special composition.

In a tunnel, planking placed against the dirt or rock walls and ceiling, outside the ribs.

Boards fastened to the back of a shovel for blast protection.

Lagging, split. Drum lagging made in two

pieces to allow changing it without dismantling the drum.

Land. A backfurrow.

Land Leveler. A towed scraper with a bottomless bucket centrally mounted in a long frame. Used chiefly in agricultural grading.

Land Tile. Porous clay pipe with open (butt) joints.

Laminated. In thin parallel layers.

Lantern. In a centrifugal pump, a hollow casing on the engine side of the pump body.

Lapped. Overlapped and fitted together.

Lay. The direction of twist in wires and strands in wire rope.

Lay, lang. A wire rope construction in which the wires are twisted in the strands in the same direction as the strands are twisted in the rope.

Lay, regular. A wire rope construction in which the direction of twist of the wires in the strands is opposite to that of the strands in the rope.

Layshaft. A fixed shaft supporting revolving drums.

Lead (Leader). In a pile driver, the usually vertical hanging beam that guides the hammer and the pile.

Lead Wires. In blasting, the heavy wires that connect the firing current source or switch with the connecting or cap wires.

Leg. A side post in tunnel timbering.

A wire or connector in one side of an electrical circuit.

Level. To make level or to cause to conform to a specified grade.

Any instrument that can be used to indicate a horizontal line or plane.

Leveling Rod (Surveying). A telescoping rod marked in feet and fractions of feet, and fitted with a movable target or sighting disc.

Lever. A bar that pivots so that force applied at one part can do work at another, usually with a change in the force-distance ratio.

Lever, first class. A bar having a fulcrum (pivot point) between the points where force is applied and where it is exerted.

Lever, second class. A lever whose force is exerted between the fulcrum and the point where it is applied.

Lever, third class. A lever to which force is applied between the fulcrum and the work point.

Lift. A step or bench in a multiple layer excavation.

Line. A cable, rope, chain, or other flexible device for transmitting pull.

To line pieces up in order to couple them together.

Line, drilling. In a churn drill, the cable that supports and manipulates the tools.

Line Oiler. An oil reservoir and metering device placed in a compressed air line to lubricate air tools.

Line, spinning. A line wrapped around a threaded pipe, so that a pull will rotate the pipe to fasten or unfasten it from another.

Lip. The cutting edge of a bucket. Applied chiefly to edges including tooth sockets.

Liquid Limit. Minimum moisture content which will cause soil to flow if jarred slightly.

Load. To place explosives in a hole.

To transfer material to a hauling unit or hopper.

Load Binder. A lever that pulls two grab hooks together, and holds them by locking over center.

Load, deck. Charges of dynamite spaced well apart in a borehole, and fired by separate primers or by detonating cord.

Load Factor. Average load carried by an engine, machine, or plant, expressed as a percentage of its maximum capacity.

Loader, belt (Elevating grader). A machine whose forward motion cuts soil with a plowshare or disc and pushes it to a conveyor belt that elevates it to a dumping point.

Loader, bucket. A machine having a digging and gathering rotor, and a set of chain mounted buckets to elevate the material to a dumping point.

Loader, front end. A tractor loader that both digs and dumps in front.

Loader, paddle. A belt loader equipped with chain driven paddles that move loose material to the belt.

Loader, reversed. A front end loader mounted on a wheel tractor having the driving wheels in front and steering at the rear.

Loader, swing. A tractor loader that digs in front, and can swing the bucket to dump to the side of the tractor.

Loader, tower. A front end loader whose bucket is lifted along tracks on a more or less vertical tower.

Loader, tractor. A tractor equipped with a digging bucket that can dump into hauling equipment.

Loam. A soft, easily worked soil containing sand, silt, and clay.

Lock. In a compressed air system, a chamber that can be opened to pressure air at one end, and to atmospheric air at the other.

Logging Tongs. Tongs with end hooks that dig in when the tongs are pulled.

Loose Yards. Measurement of soil or rock after it has been loosened by digging or blasting.

Low Bed. A machinery trailer with a low deck.

Lug Down. To slow down an engine by increasing its load beyond its capacity.

MA (Mechanical advantage). Increase in force obtained at the expense of speed or distance.

Machined. A smooth surface finish on metal. Shaped by cutting or grinding.

Magazine. A structure or container in which explosives are stored.

Manifold. A chamber or tube having a number of inlets and one outlet, or one inlet and several outlets.

Mass Diagram. A plotting of cumulative cuts and fills used for engineering computation of highway jobs.

Mass Profile. A road profile showing cut and fill in cubic yards.

Mass Shooting. Simultaneous exploding of charges in all of a large number of holes, as contrasted with firing in sequence with delay caps.

Mast. A tower or vertical beam carrying one or more load lines at its top.

Mastic. A soft sealing material.

Mat. A heavy, flexible fabric of woven wire rope or chain used to confine blasts.

A wood platform used in sets to support machinery on soft ground.

Mechanical Efficiency. As applied to engines it is the ratio of the useful horsepower available at the flywheel or power takeoff to the horsepower developed in the engine cylinders, expressed in percent.

Mesh. In wire screen, the number of openings per lineal inch.

Metering Pin. A valve plunger that controls the rate of flow of a liquid or a gas.

Millwright. A mechanic specializing in installation of heavy machinery in permanent plants.

Military Crest. A ridge that interrupts the view between a valley and a hilltop.

Millisecond Delay (Short period delay). A type of delay cap with a definite but extremely short interval between passing of current and explosion.

Mining. Usually removal of soil or rock having value because of its chemical composition.

Misfire. Failure of all or part of an explosive charge to go off.

Mixed Face. In tunneling, digging in dirt and rock in the same heading at the same time.

mm. Millimeter.

Mole (Mole ball). An egg-shaped device pulled behind the tooth of a subsoil plow to open drainage passages.

Moldboard. A curved surface of a plow, dozer, or grader blade, or other dirt mover, which gives dirt moving over it a rotary, spiral, or twisting movement.

Monitor (Giant). In hydraulicking, a high pressure nozzle mounted in a swivel on a skid frame.

Mouse Hole. In a rotary drill substructure, a socket that holds a single piece of drill pipe ready to be added to the string.

Muck. Mud rich in humus.

Finely blasted rock, particularly from underground.

Mud. Generally any soil containing enough water to make it soft.

In rotary drilling, a mixture of water with fine drill cuttings and added material, which is pumped through the drill string to clean the hole and cool the bit.

Mudcapping. Blasting boulders or other rock by means of explosive laid on the surface and covered with mud.

Multi Use Bit. A detachable drill bit that can be sharpened and reshaped when worn.

Multiple Lines. A single line reeved around two or more sheaves so as to increase pull at the expense of speed.

Net Cut. In sidehill work, the cut required less the fill required at a particular station or part of a road.

Net Fill. The fill required, less the cut required, at a particular station or part of a road.

New York Rod. A leveling rod marked with narrow lines, ruler-fashion.

Nip. The seizing of stone between the jaws or rolls of a crusher.

Nip, angle of. In a roll crusher, the angle between tangents to the roll surfaces at the widest point at which they will grip a stone.

Nipple. A short piece of pipe with male threads on each end.

Nipple, close. A nipple so short that its two sets of threads meet in the middle.

Nitroglycerin. A powerful liquid explosive that is dangerously unstable unless combined with other materials.

Normal Haul. A haul whose cost is included in the cost of excavation, so that no separate charge is made for it.

Octane Number. Percent of iso-octane by volume in a mixture of iso-octane and normal heptane that has the same anti-knock character in a standard variable compression Cooperative Fuel Research test engine as the fuel under test. Octane has anti-knock characteristics. A mixture having 75% octane and 25% heptane is said to have an octane rating of 75.

Off-Set Digging. In a ladder ditcher, digging with the boom not centered in the machine.

OHM. Unit of electrical resistance to current flow. It is equal to a fall in potential of 1 volt when a current of 1 amp. flows.

Oil. Any fluid lubricant.

Any liquid petroleum derivative that is less volatile than gasoline.

One on Two (One to two). A slope in which the elevation rises one foot in two horizontal feet.

One Part Line. A single strand of rope or cable.

Open-Cut. A method of excavation in which the working area is kept open to the sky. Used to distinguish from cut-and-cover and underground work.

Optimum. Best.

Ore. Rock or earth containing workable quantities of a mineral or minerals of commercial value.

Oscillation. Independent movement through a limited range, usually on a hinge.

Outrigger. An outward extension of a frame which is supported by a jack or block. Used to increase stability.

Overbreak. Moving or loosening of rock as a result of a blast, beyond the intended line of cut.

Overburden. Soil or rock lying on top of a pay formation.

Overhang. Projecting parts of a face or bank.

Overhaul. In many highway contracts, a movement of dirt far enough so that payment, in addition to excavation pay, is made for its haulage.

Overhead Shovel. A tractor loader which digs at one end, swings the bucket overhead, and dumps at the other end.

Overtopping. Flow of water over the top of a dam or embankment.

Overwinding. A rope or cable wound and attached so that it stretches from the top of a drum to the load.

Pad (Shoe or plate). Ground contact part of a crawler-type track.

Pan. A carrying scraper.

Parallel. An arrangement of electric blasting caps in which the firing current passes through all of them at the same time.

Parallel Series. Two or more series of electric blasting caps arranged in parallel.

Part Swing Shovel. A shovel in which the upper works can rotate through only part of a circle.

Parts of Line. Separate strands of the same rope or cable used to connect two sets of sheaves.

Pass. A working trip or passage of an excavating or grading machine.

Paving Breaker. An air hammer which does not rotate its steel.

Pawl. A tooth or set of teeth designed to lock against a ratchet.

Pay Formation. A layer or deposit of soil or rock whose value is sufficient to justify excavation.

Peat (Humus). A soft light swamp soil consisting mostly of decayed vegetation.

Peg Point (Steady point). A pointed bar in a slide clamp. Used to brace a machine during work.

Pellet Powder. Black powder made up into hollow cartridges.

Peeler. One of a set of blades that pick up and channel water moved outward by the impeller of a centrifugal pump.

Perched Water Table. Underground water lying over dry soil, and sealed from it by an impervious layer.

Permissible. Low-flame explosive used in gassy and dusty coal mines.

Petcock. A small drain valve.

pH. Percentage of free hydrogen ions. A measurement of soil acidity. pH 7 is neutral, smaller readings increasingly acid.

Philadelphia Rod. A leveling rod in which the hundredths of feet, or eighths of inches, are marked by alternate bars of color the width of the measurement.

Pig. An air manifold having a number of pipes which distribute compressed air coming through a single large line.

Pilot Valve. In a compressor, an automatic valve which regulates air pressure.

Pillow Block. A metal-cased rubber block that allows limited motion to a support or thrust member.

Pin, track. A hinge pin connecting two sections or shoes of a crawler track.

Pin, master. The only pin in an integrated crawler track that will open the track when driven out.

Pin, taper. A straight-sided pin that is smaller at one end than at the other.

Pin Thread. The male side of A.P.I. tapered thread.

Pintle. A vertical pin fastened at the bottom that serves as a center of rotation.

Pintle Hook. A towing device consisting of a fixed lower jaw, a hinged and lockable upper jaw, and a socket between them to hold a tow ring.

Pioneering. The first working over of rough or overgrown areas.

Pioneer Road. A primitive, temporary road built along the route of a job, to provide means for moving equipment and men.

Piston Displacement. The amount of air displaced by moving all pistons of an engine or compressor from the bottom to the top of their stroke.

Piston, free running. A piston not connected with a rod, that does its work by hammer-like blows.

Piston, slave. A small piston having a fixed connection with a larger one.

Piston Speed. Total feet of travel of a piston in one minute.

Pi (π) A number, approximately 3.1416 or $3\frac{1}{7}$, which when multiplied by the diameter of a circle, will give the circumference.

Pit. Any mine, quarry, or excavation area worked by the open-cut method to obtain material of value.

Pit, dig-down (Sunken pit). A pit that is below the surrounding area on all sides.

Pitman Arm. An arm having a limited movement around a pivot.

Pivot. A non-rotating axle or hinge pin.

Pitch. The slope of a surface or tooth relative to its direction of movement.

In a roller or silent chain, the space between pins, measured center to center.

Pitch Arms (Pitch braces) (Pitch rods). Rods, usually adjustable, which determine the digging angle of a blade or bucket.

Pivot Tube. A hollow hinge pin.

Pivot Shaft. A tractor dead axle, or any fixed shaft which acts as a hinge pin.

Planimeter. A device that measures an area on a map when run around its edges.

Plate, pressure. A flywheel-driven plate that can be slid along a clutch shaft to squeeze a lined plate against the flywheel.

Platform. A wood mat used in sets to support machinery on soft ground. Also called a pontoon.

An operator's station on a large machine, particularly on rollers.

Plastic Limit. The minimum amount of water in terms of percent of oven-dry weight of soil that will make the soil plastic.

Plastic Soil. A soil that can be rolled into ⅛" diameter strings without crumbling.

A soft, rubbery soil.

Plenum. Use of compressed air to hold soil from slumping into an excavation.

Plug. A stoppage in the discharge line of a dredge, or in an underground drain.

Plug and Feathers. A set of two half-round pieces of hard steel and a gradual-taper wedge, used for splitting drilled boulders.

Plug, magnetic. A drain or inspection plug magnetized for the purpose of attracting and holding iron or steel particles in lubricant.

Plumb Bob. A pointed weight hung from a string. Used for vertical alignment.

Plumbers' Dope. A soft sealing compound for pipe threads.

Ply. One of several layers of fabric or of other strength-contributing material.

Pneumatic. Powered or inflated by compressed air.

Point, well. A pipe having a fine mesh screen and a drive point at the bottom. Used for pumping out ground water.

Pond. A small lake.

In dredge work, an area where discharge water is held long enough to allow fine soil particles to settle.

Pontoon. A float supporting part of a structure, such as a bridge.

A wood platform used to support machinery on soft ground.

Poppet Valve. A valve shaped like a mushroom, resting on a circular seat, and opened by raising the stem. Standard automotive equipment.

Port. Left side of a ship or boat.

Portal. A nearly level opening into a tunnel.

Pot Hole. A small steep-sided hole, usually with underground drainage.

Poured Fitting. A connecting device which is fastened to the end of a cable (wire rope) by inserting the cable end in a funnel shaped socket, separating the wires and filling the socket with molten zinc.

Power Arm. The part of a lever between the fulcrum and the point where force is applied to the lever.

Power Control Unit. One or more winches mounted on a tractor and used to manipulate parts of bulldozers, scrapers, or other machines.

Power-Divider. A non-spin differential.

Power Takeoff. A place in a transmission or engine to which a shaft can be so attached as to drive an outside mechanism.

Power Train. All moving parts connecting an engine with the point or point where work is accomplished.

Powder. Black powder or gunpowder.

General term for explosives including dynamite, but excluding caps.

Powder, black. A mixture consisting mostly of carbon, sodium or potassium nitrate, and sulphur, used as an explosive.

Preform. In wire rope, to shape the wires so that they will lie in place.

Pre-Selective. An arrangement by which a gear lever can be moved, but the resulting speed shift will not take place until the clutch or the throttle is manipulated.

Pressure Plate. In a clutch, a plate driven by the flywheel or rotating housing, which can be slid toward the flywheel to engage the lined disc or discs between them.

Primacord. Trade marked name for a detonating fuse.

Prime. To provide means to start a process, as to supply sufficient water to a pump to enable it to start pumping. In blasting, to place a detonator in a cartridge or charge of explosive.

Primer. Usually the combination of a dynamite cartridge and a detonating cap.

Prime Mover. A tractor or other vehicle used to pull other machines.

Primary Excavation. Digging in undisturbed soil, as distinguished from rehandling stockpiles.

Profile. A charted line indicating grades and distances, and usually depth of cut and height of fill for excavation and grading work. It is commonly taken along the centerline.

Projected Pipe. A pipe laid on the surface before building a fill that buries it.

Propogation. Spread of an explosion through separated charges by concussion waves in water or mud.

Propel Shaft. In a revolving shovel, a shaft which transmits engine power to the walking mechanism.

Propeller Shaft. Usually a main drive shaft fitted with universal joints.

Prospecting, seismic. Underground exploration conducted by measuring vibrations caused by explosions set off in drill holes.

Protractor. A device for measuring angles on drawings.

P.S.I. (psi). Pressure in pounds per square inch.

P.T. Pipe thread.

Puddle. To compact loose soil by soaking it and allowing it to dry.

Puff Blowing. Blowing chips out of a hole by means of exhaust air from the drill.

Pull. To loosen the rock around the bottom of a hole by blasting. Usually used with a negative to describe a blast which did not shatter rock to the desired depth.

Pulley. A wheel that carries a cable or belt on part of its surface.

Pull Shovel (Dragshovel or hoe). A shovel with a hinge-and-stick mounted bucket that digs while being pulled inward.

Pump, centrifugal. A pump that moves water by centrifugal force developed by rapid rotation of an impeller.

Pump, diaphragm. A pump that moves water by reciprocating motion of a diaphragm in a chamber having inlet and outlet check valves.

Pump, jetting. A water pump that develops very high discharge pressure.

Pump, mud (Slush pump). The circulating pump that supplies fluid to a rotary drill.

Pump, well point. A centrifugal pump that can handle considerable quantities of air, and is used for removing underground water to dry up an excavation.

Pumping. Mechanical transfer of fluids.

Alternately raising and lowering a digging edge to increase the volume of dirt being transported.

Pulpwood. Wood to be used in making paper.

Pusher. A tractor that pushes a scraper to help it pick up a load.

Quadrant. A quarter of the circumference of a circle.

A curved guide for a lever.

A curved scale for measuring angles.

Quarry. A rock pit.

An open cut mine in rock chosen for physical rather than chemical characteristics.

Quarter Octagonal. A square shaft with corners cut back.

Quicksand. Fine sand or silt that is prevented from settling firmly together by upward movement of ground water.

Any wet inorganic soil so unsubstantial that it will not support any load.

Quill Shaft. A light drive shaft inside a heavier one, and turning independently of it.

Rat Hole. In a rotary drill substructure, a socket that supports the kelly and swivel when they are not in use.

Races. The inner and outer rings of a ball or roller bearing.

Radial. Lines converging at a single center.

Radius. Horizontal distance from the center of rotation of a crane to its hoisting hook.

Rake Blade. A dozer blade or attachment made of spaced tines.

Rake, brush. A rake blade having a high top and light construction.

Rake, rock. A heavy duty rake blade.

Rail. A piece of railroad type track.

The chain or inner surface of a crawler track.

Raise. A shaft being dug upward from a tunnel.

Ram. A hydraulic cylinder.

The moving weight in a pile driving hammer.

Ram, one way or single acting. A hydraulic cylinder in which fluid is supplied to one end so that the piston can be moved only one way by power.

Ram, two way or double acting. A hydraulic cylinder in which fluid can be supplied to either end, so the piston can be moved by power in two directions.

Ramp. An incline connecting two levels.

Range Pole. A pole marked in alternate red and white bands one foot high.

Ratchet. A set of teeth which are vertical on one side and sloped on the other, which will hold a pawl moving in one direction, but allow it to move in another.

Ratio of Reduction. The relationship between the maximum size of the stone which will enter a crusher, and the size of its product.

Reamer. A cutting device that enlarges or straightens a hole.

Reamer Shell. A cutter just above a diamond bit, used to assure a full-size hole.

Rearing. Rising of the front of a tractor when pulling a heavy load.

Receiver. The air tank or reservoir on a compressor.

Reciprocating. Having a straight back-and-forth or up-and-down motion.

Reduction, double. Two sets of gears in series that both reduce speed and increase power.

Reduction, single. A gear set that causes one shaft to turn another at reduced speed.

Reclaiming. Digging from stockpiles.

Reprocessing previously rejected material.

Reel. A revolving rack used for storage of hose and cable.

In a churn drill, the winches are usually called reels.

Reel, bull (Spudding reel). The churn drill winch that lifts and lowers the drill string.

Reel, calf (Casing reel). The churn drill winch used for handling casing and for odd jobs.

Reel, dead. A storage reel.

Reel, live. A reel that supplies air, water, or electricity to the inner end of the hose or wire wound on it.

Reel, sand. In a churn drill, the high speed winch that lifts the bailing cylinder.

Reeving. Threading or placement of a working line.

Relay. A valve or switch that amplifies or restores original strength to an air, hydraulic, or electrical impulse.

Relief Holes. Holes drilled closely along a line, which are not loaded, and which serve to weaken the rock so that it will break along that line.

Relief Valve. A valve which will allow air or fluid to escape if its pressure becomes higher than the valve setting.

Retaining Wall. A wall separating two ground levels.

Retract. The mechanism by which a dipper shovel bucket is pulled back out of the digging.

Reverse Bend. To bend a line over a drum or a sheave, and then in the opposite direction over another sheave.

Reversing Clutch. A forward-and-reverse transmission which is shifted by a pair of friction clutches.

Revetment. A wall sloped back sharply from its base.

A masonry or steel facing for a bank.

Revolving Shovel. A digging machine in which the upper works can revolve independently of the supporting unit.

Rheostat. A device that regulates flow of electricity by varying the amount of resistance in the circuit.

Rib. A ridge projecting above grade in the floor of a blasted area.

Ridge Terrace. A ridge built along a contour line of a slope to pond rainwater above it.

Rifling. Forming a spiral thread on the wall of a drill hole, which makes it difficult to pull out the bit.

Rifle Bar. A cylinder with curved splines.

Rifle Nut. A splined nut that slides back and forth on a rifle bar.

Rig. A general term, denoting any machine. More specifically, the front or attachment of a revolving shovel.

Riprap. Heavy stones placed at water's edge to protect soil from waves or current.

Riparian Rights. Rights of a land owner to water on or bordering his property, including right to prevent diversion or misuse of upstream water.

Ripper. A towed machine equipped with teeth, used primarily for loosening hard soil and soft rock.

Road Metal. Crushed stone used in road surfaces.

Hard pavement.

Roadster. Low priced model of a scraper or a truck.

Rob. To remove part of an installation for use elsewhere.

To take out supporting pillars or walls of pay rock in a mine.

Rock. The hard, firm, and stable parts of earth's crust.

Any material which requires blasting before it can be dug by available equipment.

Rocker Arm. A lever resting on a curved base so that the position of its fulcrum moves as its angle changes.

A bell crank with the fulcrum at the bottom.

Rocking. Pushing a resistant object repeatedly, and backing or rolling back between pushes to allow it to reach or cross its original position.

Rod Stock. Round steel rod.

Roll. The wheel of a roller.

Roll, compression. The drive wheel of a roller.

Roll, guide. The front or steering wheel of a roller.

Roller, hook. In a revolving shovel, a roller attached by a bracket to the revolving section, and contacting the lower face of a circular track on the travel unit.

Roller, support. In a crawler machine, a roller that supports the slack upper part of the track.

Roller, swing. In a revolving shovel, one of several tapered wheels that roll on a circular turntable and support the upper works.

Roller, track. In a crawler machine, the small wheels that rest on the track and carry most of the weight of the machine.

Roller, truck. A track roller.

Root Buttress. A root that is above ground where it joins the trunk.

Root Hook. A very heavy hook designed to catch and tear out big roots when it is dragged along the ground.

Rooter. A heavy duty ripper.

Rotary Table. The part of a rotary drill which turns the kelly and drill string.

Rotation Firing. Crushing a small piece of rock with a first explosion, and timing other holes to throw their burdens toward the space made by that and other preceding explosions. Or row shooting.

Rotary (Rotary table). In a rotary drill, the unit that turns the kelly and drill string.

Rotary Tiller. A machine that loosens and mixes soil and vegetation by means of a high speed rotor equipped with tines.

Rotor. Any unit that does its work in a machine by spinning, and does not drive other parts mechanically.

Round. A blast including a succession of delay shots.

Row Shooting. In a large blast, setting off the row of holes nearest the face first, and other rows behind it in succession.

R.P.M. or *rpm.* Revolutions per minute.

Rubble Drains. French drains.

Rule of Thumb. A statement or formula that is not exactly correct, but is accurate enough for use in rough figuring.

Run Levels. To survey an area or strip to determine elevations.

Running. Operating, particularly a drill.

Saddle Block. In a dipper shovel, the boom swivel block through which the stick slides when crowded or retracted.

Sand. A loose soil composed of particles between $\frac{1}{16}$ mm and 2 mm in diameter.

Rock chips and other waste produced by drilling action.

Sandhog. A man who works in compressed air.

Safety Clutch. A clutch that slips instead of transmitting loads beyond the capacity of the machine.

Safety Factor. The ratio between breakage resistance and load.

Scaling. Prying loose pieces of rock off a face or roof to avoid danger of their falling unexpectedly.

Scalping Screen. Usually a vibrating grizzly.

Scarifier. An accessory on a grader, roller, or other machine, used chiefly for shallow loosening of road surfaces.

Scavenge. To clean out thoroughly.

To pick up surplus fluid and return it to a circulating system.

Schematic. Showing principles of construction or operation, without accurate mechanical representation.

Scoria. Cinderlike lava filled with bubbles.

Brick-like material formed by volcanic heating of clay beds.

Scour. Erosion in a stream bed, particularly if caused or increased by channel changes.

Scraper (Carrying scraper) (Pan). A digging, hauling, and grading machine having a cutting edge, a carrying bowl, a movable front wall (apron) and a dumping or ejecting mechanism.

Scraper, bottom dump. A carrying scraper that dumps or ejects its load over the cutting edge.

Scraper, drag. A digging bucket operated on a cable between a mast and an anchor, that is not lifted off the ground during a normal cycle.

A two wheel tractor-towed scraper equipped with a bottomless bucket.

Scraper, rear dump. A two wheel scraper that dumps at the rear.

Scraper, self powered. A scraper built into a single unit with a tractor.

Scraper, two axle. A full trailer type carrying scraper.

Screen. A mesh or bar surface used for separating pieces or particles of different sizes.

A filter.

Screen, deck. Two or more screens placed one above the other for successive processing of the same run of material.

Screen, scalping. A coarse primary screen or grizzly.

Screen, shaking. A screen that is moved with a back-and-forth or rotary motion to move material along it and through it.

Screen, vibrating. A screen that is vibrated to move material along it and through it.

Seam. A layer of rock, coal, or ore.

Sectio.ı. An area equal to 640 acres or 1 square mile.

A part of a work area or strip.

Seepage. Movement of water through soil without formation of definite channels.

Seize. To bind wire rope with soft wire, to prevent it from ravelling when cut.

Selective Digging. Separating two or more types of soil while digging them.

Semi-Grouser. A crawler track shoe with one or more low cleats.

Semi-Trailer. A towed vehicle whose front rests on the towing unit.

Serrated. (An edge) cut into a line of teeth.

Series. An arrangement of electric blasting caps in which all the firing current passes through each of them in a single circuit.

Set. The distance a pile penetrates with one blow from the driving hammer.

Set, timbering. A tunnel support consisting of a roof beam or arch, and two posts.

Sewer Tile. Glazed waterproof clay pipe with bell joints.

Shackle. A connecting device for lines and draw bars which consists of a U shaped section pierced for a cross bolt or a pin.

Shaft. A round bar that rotates or provides an axis of revolution.

A vertical or steeply inclined tunnel.

Shaft, cam (Camshaft). A shaft carrying cams which open and close valves.

Shaft, counter (Countershaft). A shaft that allows one end of a (main) shaft to drive the other through reduction gears.

Shaft, crank (Crankshaft). The main shaft of a piston-type engine, that converts reciprocating motion into rotation.

Shaft, idler. A shaft that carries a gear that reverses direction of rotation in a transmission.

Shaft, input. The shaft that delivers engine power to a transmission or clutch.

Shaft, jack (Jackshaft). A short driveshaft, usually connecting a clutch and a transmission.

Shaft, lay. A fixed shaft supporting rotating drums or gears.

Shaft, main (Mainshaft). The transmission shaft forming a continuation of the input shaft.

Shaft, output. A shaft that transmits power from a transmission or clutch.

Shaft, reversing. A shaft whose direction of rotation can be reversed by use of clutches or brakes.

Shaking Screen. A suspended screen which is moved with a back-and-forth or rotary motion with a throw of several inches or more.

Shale. A rock formed of consolidated mud.

Shale Pit. A dumping place for coarse material screened out of rotary drill mud.

Shale Shaker. A screen in the mud circulating system of a rotary drill.

Shank (Standard). The connecting bar between a ripper or scarifier tooth and the frame.

The part of drill steel that fits into the drill.

Sheave (pronounced "shiv"). A grooved wheel used to support cable or change its direction of travel.

Sheave, traveling. A sheave block that slides in a track.

Sheave, padlock. The bucket sheave on a dipper or hoe shovel.

A sheave set connecting inner and outer boom lines.

Sheave Block. A pulley, and a case provided with means to anchor it.

Sheepsfoot. A tamping roller with feet expanded at their outer tips.

Sheet Erosion. Lowering of land by nearly uniform removal of particles from its entire surface by flowing water.

Sheeting Jacks. Push-type turnbuckles, used to set ditch bracing.

Sheet Piling. Steel strips shaped to interlock with each other when driven into the ground.

Sheeting. ⅞" tongue and groove board.

Planks used in shoring and bracing.

Sheeting Driver. An air hammer attachment that fits on plank ends so that they can be driven without splintering.

Shift. A work period.

Shift, graveyard. Work "day" from midnight to 8:00 A.M.

Shift, swing. Work "day" from 4:00 P.M. to midnight.

Occasionally refers to the midnight to 8:00 A.M. shift.

Shipper Shaft. In a dipper shovel, the hinge on which the stick pivots when the bucket is hoisted.

Shoe. A ground plate forming a link of a track, or bolted to a track link.

A support for a bulldozer blade or other digging edge to prevent cutting down.

A cleanup device following the buckets of a ditching machine.

Shoe, tile. A box towed behind a ditching machine, in which tile can be laid on the ditch bottom.

Shot Rock. Blasted rock.

Shoot. Blast.

Shoring. Temporary bracing to hold the sides of an excavation from caving.

Shovel. A digging and loading machine or tool.

Shovel, dipper (Shovel) (Dipper stick). A revolving shovel that has a push type bucket rigidly fastened to a stick that slides on a pivot in the boom.

Shovel Dozer (Dozer shovel). A tractor equipped with a front-mounted bucket that can be used for pushing, digging, and truck loading.

Shovel, hoe (Dragshovel, pullshovel, ditching shovel, backhoe). A revolving shovel having a pull-type bucket rigidly attached to a stick hinged on the end of a live boom.

Shovel, hydraulic. A revolving shovel in which drums and cables are replaced by hydraulic rams and/or motors.

Shovel, part swing. A revolving shovel that cannot swing through a full circle.

Shovel, revolving. A digging machine that has the machinery deck and attachment on a vertical pivot, so that it can swing independently of its base.

Shoulder. The graded part of a road on each side of the pavement.

The side of a horizontal pipe, at the level of the center line.

Shrinkage. Loss of bulk of soil when compacted in a fill. Usually is computed on the basis of bank measure.

Shunt. A connection between the two wires of a blasting cap which prevents building up of opposed electric potential in them.

Shuttle. A back and forth motion of a machine which continues to face in one direction.

Sidecasting. Piling spoil alongside the excavation from which it is taken.

Side Hill. A slope that crosses the line of work.

Sidehill Cut. A long excavation in a slope that has a bank on one side, and is near original grade on the other.

Sidewalls. Walls, usually masonry, at each end of a culvert.

Silicosis. A lung disease caused chiefly by inhaling rock dust from air drills.

Silt. A soil composed of particles between 1/256 mm and 1/16 mm in diameter.

A heavy soil intermediate between clay and sand.

Silting. Filling with soil or mud deposited by water.

Silt Trap. A settling hole or basin that prevents water-borne soil from entering a pond or drainage system.

Siphon. A tube or pipe through which water flows over a high point by gravity.

Six by Six (6×6). A truck having drive to the front wheels and to tandem rear wheels.

Six Wheeler (Ten wheeler). A truck with two sets of rear axles.

Skewed. On a horizontal angle, or in an oblique course or direction.

Skip. A non-digging bucket or tray that hoists material.

Skirt (Skirt board). A vertical strip placed at the side of a conveyor belt to prevent spillage or to increase capacity.

Skiving. To dig in thin layers.

Skullcracker. A steel ball swung from a crane boom. Used for demolishing buildings and for breaking boulders.

Slab. The deck or floor of a concrete bridge.

Any horizontal section of masonry.

Slack Adjuster. In air brakes, the connection between the brake chamber and the brake cam.

Slackline (Slackline cableway). A cable excavator having a track cable which is loosened to lower the bucket, and tightened to raise it.

Slag. Refuse from steel-making.

Slave Unit. A machine which is controlled by or through another unit of the same type.

Sleeper. In corduroy roads, a cross log or timber supporting the stringers (longitudinal supports).

Slick Hole. A hole column loaded with explosive, without springing.

Slick Sheets. Thin steel plate spread on a tunnel floor before a blast, to make hand mucking easier.

Slide. A small landslide.

Slide Coupling. A slip joint.

Sling. A lifting hold consisting of two or more strands of chain or cable.

Sling Block. A frame in which two sheaves are mounted so as to receive lines from opposite directions.

Slat Bucket. A digging bucket of basket construction, used in handling sticky, chunky mud.

Slip Joint. A splined connection loose enough to allow its two parts to slide on each other to change shaft length.

Slow Powder. Black powder, often called gunpowder. Also, some of the slow acting dynamites.

Sludge Samples. Samples of mud from a rotary drill, or sand from a churn drill, used to obtain information about the formation being drilled.

Slugger. A tooth on a roll-type rock crusher.

Sluice. A steep, narrow waterway.

Slurry. Cement grout.

Slush Pump. The mud pump for a rotary drill.

Slusher. A mobile drag scraper with a metal slide to elevate the bucket to dump point.

Smart Aleck. A limit switch that cuts off power if a machine part is moved beyond its safe range.

Smoother Bar. A drag that breaks up lumps behind a leveling machine.

Snag Boat. A boat equipped with a hoist and grapple for clearing obstacles from the path of a dredge.

Snake Hole. A hole driven into a toe for blasting, with or without vertical holes.

Snakeholing. Drilling under a rock or face in order to blast it.

Snaking. Towing a load with a long cable.

Inserting a tow or hoist line under an object without moving the object.

Snatch Block. A pulley in a case which can be easily fastened to lines or objects by means of a hook, ring, or shackle.

Soil. The loose surface material of the earth's crust.

Soil, heavy. A fine grained soil, made up largely of clay or silt.

Solid Loading. Filling a drill hole with all the explosive which can be crammed into it, except for stemming space at top.

Space. In a screen, the actual dimension of the clear opening between adjacent parallel wires or bars.

Spaced Loading. Loading so that cartridges or groups of cartridges are separated by open spacers which do not prevent the concussion from one charge from reaching the next.

Spacing. The distance between drill holes along a line parallel to the face.

Spall. To break off from a surface in sheets or pieces.

Specific Gravity (Solids or liquids). The ratio of the mass of a body to an equal volume of water.

Spider Gear (Carrier pinion). A differential gear which rotates on its shaft in a rotating case.

Spile (Forepole). A plank driven ahead of a tunnel face for roof support.

Spillway. An overflow channel for a pond or a terrace channel.

Spinning Line. A chain or rope used as a wrench in attaching and detaching drill pipe sections.

Spiraling. Rifling.

A drill hole twisting into a spiral around its intended center line.

Spiral Cleaner. A device for removing dirt from a conveyor belt.

Spirit Level. A glass tube containing fluid and an air bubble.

Spline. A set of parallel grooves running lengthwise of a shaft.

Split Sprocket. A two piece sprocket that can be assembled on a shaft without removing the shaft bearings.

Spoil. Dirt or rock which has been removed from its original location.

Spool. The movable part of a slide-type hydraulic valve.

To wind in a winch cable.

Spot (Trucks). To direct to the exact loading or dumping place.

Spot Log. A log or marker placed to show a truck driver the spot where he should stop to be loaded.

Spotter. In truck use, the man who directs the driver into loading or dumping position.

In a pile driver, the horizontal connection between the machinery deck and the lead (pile guide).

Spring, helper. On a truck rear axle, an upper spring that carries no weight until the regular spring changes shape under load.

Springing. Enlarging the bottom of a drill hole by exploding a small charge in it.

Spring Line. The meeting of the roof arch and the sides of a tunnel.

Spring Loaded. Held in contact or engagement by springs.

Sprocket. A gear that meshes with a chain or a crawler track.

Spuds. On a dredge, steel tubes pointed at the bottom and provided with lifting tackle at the top which are used to hold and to move the dredge.

Spud Well. On a dredge, a pair of guide collars for a spud.

Spudding Drill (Churn drill). A drill that makes hole by lifting and dropping a chisel bit.

Spur. A rock ridge projecting from a side wall after inadequate blasting.

Spur Valley. A short branch valley.

Squib. A detonator consisting of a firing device, and a chemical that will burn with a flash which will ignite black powder.

Stab. In adding to a drill string, the action of lining up and catching the threads of the loose piece.

Stabilize. To make soil firm and to prevent it from moving.

Stadia. Measurement of distance by proportion to the space on a vertical rod seen between upper and lower instrument cross hairs. Usual proportion is one vertical to 100 horizontal.

Stake, side. On a road job, a stake on the line of the outer edge of the proposed pavement.

Any stake not on the center line.

Stake, slope. A stake marking the line where a cut or fill meets the original grade.

Stacker. A large mobile elevating belt.

Starboard. Right side of a boat.

Starter. In drilling, a short steel used to start a drill hole.

Static Balance. A condition of rest created by inertia (dead weight) sufficient to oppose outside forces.

Static Load. A load that is at rest and exerts downward pressure only.

Station. Any one of a series of stakes or points indicating distance from a point of beginning or reference.

Station, minus. Stakes or points on the far side of the zero point from which a job was originally laid out.

Stator (Reactor). In a torque converter, a set of fixed vanes that change the direction of flow of fluid entering the pump or the next stage turbine.

Steady Point (Peg point). A pointed steel bar which can be locked in a clamp, and is used to brace a drill frame against the ground.

Steel. In air hammers, the hollow or solid steel bar which connects the hammer with the cutting tool.

Steel, alloy. Steel compounded with other metals to increase strength, wearing or rust resistance, or to obtain other desired qualities.

Steel Centralizer. On a wagon drill, a guide to hold the starting steel in proper alignment.

Steel Changes. The difference in length between successive steels used in drilling one hole.

Steel Puller. A hinged clamp on the bottom of a hand drill.

Steering Brake. A brake which slows or stops one side of a tractor.

Steering Clutch. A clutch which can disconnect power from one side of a tractor.

Stemming. Dirt or other inert material placed in parts of a drill hole instead of explosives.

Stick or Handle. In a dipper shovel or pull shovel, a rigid bar hinged to the boom and fastened to the bucket.

Stockpile. Material dug and piled for future use.

Stone. Rock.

Stone Boat. A flat steel sled with an up-curved front.

Stope. An underground excavation that is made in a series of steps or benches.

Street Ell. A pipe elbow with male threads on one end, female on the other.

Strength. In an explosive, the energy content in relation to its weight.

Stress. The force per unit area. When the force is one of compression it is known as "pressure." It is an internal force which resists an external force.

String (of tools). In a churn drill, the tools suspended on the drilling cable.

String Loading. Filling a drill hole with cartridges smaller in diameter than the hole, without slitting or tamping them.

Stringer. A beam running lengthwise of a bridge or wood road.

String Level. A spirit level equipped with prongs so that it can be hung from a string.

Strip. Remove overburden or thin layers of pay material.

Stripping. Removal of a surface layer or deposit, usually for the purpose of excavating other material under it.

Stripping Shovel. A shovel with a specially long boom and stick that enable it to reach farther and pile higher.

Stoper. A hand-size air drill mounted on a column or other support.

Strut. An inside brace.

Stud. A bolt having one end firmly anchored.

Stuffing Box. A space around a shaft filled with soft packing to prevent fluids or gases from leaking along it.

Stumper. A narrow heavy dozer attachment used in pushing out stumps.

Sub (Joint protector). A threaded thread protector used with drill pipe.

Subgrade. The surface produced by grading native earth, or cheap imported materials, which serves as a base for a more expensive paving.

Subsoil Plow (Pan breaker). A one-tooth ripper designed for agricultural work.

Sub Saver. A protector for the thread protector on the kelly of a rotary drill.

Suck. The shape of the bottom of a cutting

edge or tooth which tends to pull it into the ground as it is moved.

Suction. Atmospheric pressure pushing against a partial vacuum.

The "pull" of a pump.

Adhesion of a mass of mud to the underside of an object being lifted out of it.

Sump. A low spot to which water is drained, and from which it is removed by a pump.

Sun Gear. The central gear in a planetary set.

Sun Gears. A planetary gear set consisting of a central gear, an internal-tooth ring gear, and two or more planet gears meshed with both of them.

Supercharger. A blower that increases the intake pressure of an engine.

Surge Bin. A compartment for temporary storage, which will allow converting a variable rate of supply into a steady flow of the same average amount.

Surveying. To find and record elevations, locations, and directions, by means of instruments.

Sweat. To unite two closely fitting pieces by enlarging the outer one by heat.

Swell (Growth). Increase of bulk in soil or rock when it is dug or blasted.

Swing. In revolving shovels, to rotate the shovel on its base.

In churn drills, to operate a string of tools.

Swing Angle. The distance in degrees which a shovel must swing between digging and dumping points.

Switchback. A hairpin curve.

Swivel Head. In a diamond drill, the mechanism that rotates the kelly and drill string.

Synchromesh. A silent-shift transmission construction, in which hub speeds are synchronized before engagement by contact of leather cones.

Tagline. A line from a crane boom to a clamshell bucket that holds the bucket from spinning out of position.

Tail. The rear of a shovel deck.

The anchor end of a cable excavator.

Tail Anchor. The anchor for a track cable, or the turn point for a backhaul line in a cable excavator.

Tailblock. The boom foot and idler sprocket assembly on a ladder ditcher.

Tailboard. Tailgate.

Tailgate. The hinged rear wall of a dump truck body.

The hinged or sliding rear wall of a scraper bowl.

Tailings. Second grade or waste material separated from pay material during screening or processing.

Tail Swing. The clearance required by the rear of a revolving shovel.

Talus. Loose rock or gravel formed by disintegration of a steep rock slope.

Tamp. Pound or press soil to compact it.

Tamper. A tool for compacting soil in spots not accessible to rollers.

Tamping Roller. One or more steel drums, fitted with projecting feet, and towed by means of a box frame.

Tandem. A double-axle drive unit for a truck or grader. (A bogie).

A pair in which one part follows the other.

Tandem Drive. A three-axle vehicle having two driving axles.

Tangent. A line that touches a circle and is perpendicular to its radius at the point of contact.

Taproot. A big root that grows downward from the base of a tree.

Target Rod. A leveling rod.

Tee. A pipe fitting that has two threaded openings in line, and a third at right angles to them.

Telescope. To slide one piece inside another.

Terrace. A ridge, a ridge and hollow, or a flat bench built along a ground contour.

Terrain. Ground surface.

Ten Wheeler (Six wheeler). A truck with tandem rear axles.

Three Part Line. A single strand of rope or cable doubled back around two sheaves so that three parts of it pull a load together.

Thrible. Three sections of drill pipe handled as a unit.

Thorough Cut. Through cut.

Through Cut. An excavation between parallel banks that begins and ends at original grade.

Throw. The longest straight distance moved in the stroke or circle of a reciprocating or rotary part.

Scattering of blast fragments.

Throwout Bearing. A bearing, sliding on a clutch jackshaft, that carries the engage-and-disengage mechanism.

Thrust Arm. A cable-controlled bar that can slide by power in two directions.

Thrust Washer. A washer that holds a rotating part from sideward movement in its bearings.

Tight. Soil or rock formations lacking veins of weakness.

Blasts or blast holes around which rock cannot break away freely.

Tile. Pipe made of baked clay.

Tile, land. Short pieces of porous pipe with butt (open) joints, used for underground drainage.

Tile, sewer. Glazed clay pipe with bell joints.

Tile Shoe (Tile box). A device that permits laying tile directly behind a ditcher.

Tilth. Soil condition in relation to lump or particle size.

Timber. Wood beams larger than 4 x 6.

Trees.

Timbering. Wood bracing in a tunnel or excavation.

Toe. The projection of the bottom of a face beyond the top.

Tongs. A pair of curved arms pivoted to each other, scissor fashion, so that a pull on a ring or chain connecting the short ends will cause the long ends to close to grip an object between them.

Tongue. Drawbar of a towed vehicle.

Tooth Base. The inner part of a two piece tooth on a digging bucket.

Occasionally, the socket in which a tooth fits.

Topographic Map. A map indicating surface elevation and slope.

Topsoil. The topmost layer of soil. Usually refers to soil containing humus which is capable of supporting a good plant growth.

Topping. Fine material forming a surface layer or dressing for a road or grade.

Torque. The twisting force exerted by or on a shaft, without reference to the speed of the shaft.

Torque Converter. A hydraulic coupling which utilizes slippage to multiply torque.

Torque Rod. A bar having the function of resisting or absorbing twisting strains.

Track. A crawler track.

A railroad-type track.

Track, crawler. One of a pair of roller chains used to support and propel a machine. It has an upper surface which provides a track to carry the wheels of the machine, and a lower surface providing continuous ground contact.

Tilting Dozer. A bulldozer whose blade can be pivoted on a horizontal center pin to cut low on either side.

Track Frame (Truck frame). In a crawler mounting, a side frame to which the track roller and idler are attached.

Track Roller. In a crawler machine, the small wheels which are under the track frame and which rest on the track.

Traction. The total amount of driving push of a vehicle on a given surface.

Tractive Efficiency. A measure of the proportion of the weight resting on tracks or drive wheels which can be converted into vehicle movement.

Tractor. A motor vehicle on tracks or wheels used for towing or operating vehicles or equipment.

Tractor Loader (Tractor shovel or shovel dozer). A tractor equipped with a bucket which can be used to dig, and to elevate to dump at truck height.

Trailer (Full trailer). A towed carrier which rests on its own wheels both front and rear.

Trailer, semi (Semitrailer). A towed carrier that rests on the tractor in front, and on its own wheels in the rear.

Tramp Iron. Scrap metal entering a crusher.

Transfer Case. In an all-wheel drive vehicle, a transmission or gear set that provides drive to the front shaft.

Transfer Point. Turning point.

Transit. A surveying instrument that can measure both vertical and horizontal angles.

Transmission. A gear set that permits change in speed-power ratio and/or direction of rotation.

Transmission, clutch-shifted. A constant-mesh transmission in which power is directed through gear trains by engagement of friction clutches.

Transmission, compound. A gear set in which power can be transmitted through two sets of reduction gears in succession.

Transmission, reduction-type. A transmission whose output shaft (usually the countershaft) always turns more slowly than the input shaft.

Transmission, reversing. A transmission that has only a forward and reverse shift.

Transite. Cement-asbestos pipe.

Transition Belt (Feeder conveyor). A short belt carrying material from a loading point to a main conveyor belt.

Tread. The ground contact surface on a tire or track shoe.

Occasionally, a high-friction lagging on a belt pulley.

Treadle. A foot pedal hinged to the floor at one end.

Trench. A ditch.

Trestle. A bridge, usually of timber or steel, that has a number of closely spaced supports between the abutments.

Trickle Drain. A pond overflow pipe set vertically with its open top level with the water surface.

Trim Holes (Relief holes). Unloaded drill holes closely spaced along a line to limit the breakage of a blast.

Trip. A release catch.

Tripper. A double pulley that turns a short section of a conveyor belt upside down in order to dump its load into a side chute.

Tripod. A three-legged support for a surveying instrument.

Troughing. Making repeated dozer pushes in one track, so that ridges of spilled material hold dirt in front of the blade.

Truck, bottom dump. (Dump wagon). A trailer or semitrailer that dumps bulk material by opening doors in the floor of the body.

Truck, dump. A truck or semitrailer that carries a box body with a mechanism for discharging its load.

Truck, platform (Rack body truck). A truck having a flat open body.

Truck, rear dump (End dump). A truck or semitrailer that has a box body that can be raised at the front so the load will slide out the rear.

Truck frame. Track frame.

Trunnion (Walking beam or bar). An oscillating bar which allows changes in angle between a unit fastened to its center, and another attached to both ends.

A heavy horizontal hinge.

Trussed. Braced by an assembly of members into a rigid unit.

T.U. Takeup. A mechanism for adjusting belt or chain tension.

Tub. The base of a walking dragline.

Turbine. A rotary engine driven by pressure of liquid or gas against its vanes.

Turn Angles. To measure the angle between directions with a surveying instrument.

Turning Point (Transfer point). A point whose elevation is taken from two or more instrument positions to determine their height in relation to each other.

Turntable. A base that supports a part and allows it to rotate or swing.

In a shovel, the upper part of the travel unit.

Two Part Line. A single strand of rope or cable doubled back around a sheave so that two parts of it pull a load together.

Universal Joint. A connection between two shafts that allows them to turn or swivel at an angle.

Upset. To enlarge an end of a bar by shortening it.

Vein. A layer, seam, or narrow irregular body of material different from surrounding formations.

Venturi. A pressure jet that draws in and mixes air.

Vernier. A device permitting finer measurement or control than standard markings or adjustments.

In a spudding drill, a brake adjustment that permits the line to pay out automatically as the hole deepens.

Vertical Curve. The meeting of different gradients in a road or pipe.

Vertical Drains. Usually columns of sand used to vent water squeezed out of humus by weight of fill.

Viaduct. A bridge, usually of concrete, that is supported on piers between its abutments.

Vibrating Screen. A screen which is vibrated to separate and move pieces resting on it.

Viscosity. The resistance of a fluid to flow. A liquid with a high viscosity rating will resist flow more readily than will a liquid with a low viscosity. The Society of Automotive Engineers (S.A.E.) has developed a series of viscosity numbers for indicating viscosities of lubricating oils.

Vitrify. Glaze during heat treatment.

Volt. The electromotive force which will cause a current of one ampere to flow through a resistance of one ohm.

Voltage (Potential). Electromotive force.

Volumetric Efficiency. In compressors, the relationship between c.f.m. and piston displacement.

Wadding. Paper or cloth placed over explosive in a hole.

Wagon. A trailer with a dump body.

Wagon Drill. A wheeled frame holding a pneumatic drill and a mechanism for feeding it into the rock and retracting it.

Walker. A walking dragline.

Walking Beam (Trunnion). A rigid member whose ends rest on supports that may move up and down independently, and whose center is hinged to the load it carries.

Walking Bar. A trunnion or walking beam.

Walking Dragline. A dragline shovel which drags itself along the ground by means of side mounted shoes.

Wash Boring. A test hole from which samples are brought up mixed with water.

Waste. Digging, hauling and dumping of valueless material to get it out of the way; or the valueless material itself.

Watershed. Area which drains into or past a point.

Water Table. The surface of underground, gravity-controlled water.

Watt. The power of a current of one ampere flowing across a potential difference of one volt.

Wedge. A piece that tapers from a thick end to a chisel point.

Weld. To build up or fasten together metals by bonding on molten metal.

Well. A slot in the front of a hydraulic dredge hull in which the digging ladder pivots.

A wall around a tree trunk that protects it from fill.

Well Drill. A churn drill used for water wells. It usually has a limited depth capacity and a truck or trailer mounting.

Well Point. A pipe fitted with a driving point and a fine mesh screen, used to remove underground water.

A complete set of equipment for drying up ground, including well points, connecting pipes and a pump.

Weldment. A base or frame made of pieces welded together, as contrasted with a one piece casting or a bolted or riveted assembly.

Wetting Agent. A chemical that reduces the surface tension of water so that it soaks into porous material more readily. Example—synthetic soap powder.

Whaler. A horizontal beam in a bracing structure.

Wheel, track (Truck wheel). One of a set of small flanged steel wheels resting on a crawler track and supporting a track frame.

Wheel, bull. A driving sprocket for a crawler track.

Wheel Ditcher. A wheel equipped with digging buckets, carried and controlled by a tractor unit.

Winch. A drum that can be rotated so as to exert a strong pull while winding in a line.

Winch, capstan (Cat head). A revolving spool

that exerts a pull by friction with one or more loops of fiber rope.

Winch, donkey (Yarder). A two drum towing winch.

Winch, oil field. An extremely powerful low speed winch on a crawler tractor.

Winch, power control (Power control unit). A high speed tractor mounted winch with one to three drums. Used chiefly for operation of bulldozers, scrapers, and rooters.

Winch, towing (Logging winch). A heavy duty winch mounted on the rear of a crawler tractor.

Window Pipe. A dredge discharge pipe with one or more openings in the bottom.

Windrow. A ridge of loose dirt.

Wing. Projection on an air drill bit.

Wing Wall. A wall that guides a stream into a bridge opening or culvert barrel.

Work Arm. The part of a lever between the fulcrum and the working end.

Working Cycle. A complete set of operations. In an excavator, it usually includes loading, moving, dumping, and returning to the loading point.

Working Drawing. Any drawing showing sufficient detail so that whatever is shown can be built without other drawings or instructions.

Worm. A gear formed of a cylinder with spiral threads cut in its surface.

Worm Wheel. A modified spur gear with curved teeth that meshes with a worm.

Wrist Action. In a bucket, the ability to change its digging or dumping angle by power.

INDEX

INDEX

Listings in this index are arranged according to the word by word method, so that all entries beginning with one word are completed before starting those that begin with a different word or a changed form of the same word. For example, "tail swing" precedes "tailings."

Abbreviations and sets of initials are treated as single words, so that "c.f.m." is found after "caving." When there is a question about whether a compound word such as "backhoe" or "centerline" is one word or two, it has been divided and treated as two. However, when a term has grown so firmly together that its meaning changes when separated, as "dragline," it is placed as a single word.

Occasional small liberties have been taken with alphabetical sequence in order to keep a related series together.

Arrangement of double headings is not consistent, as it has followed the assumed interest and phraseology of those using the index. Most men think of a dipper shovel as a shovel, so the principal listing is given under "Shovel, dipper." On the other hand, the hoe shovel is considered primarily a hoe, so is detailed under "hoe." Cross references are supplied. Short listings are often duplicated, long ones may be abbreviated under the secondary heading.

For convenience in reference, the chapters are listed here:

Chapter
1 Land Clearing (and fire fighting)
2 Levels and Locations (surveying)
3 Soil and Mud (and stuck machinery)
4 Cellars
5 Ditching and Dewatering (ditches, drains, pipes, pumping)
6 Ponds
7 Landscaping, and Agricultural Grading
8 Roads (including scraper work, and figuring yardage)
9 Rock Blasting and Tunneling
10 Pit Operation (digging and handling salable dirt)
11 Making and Losing Money
12 Hints on Maintenance

Appendix (A) Tables, charts, and technical information

Boldface type is used to emphasize the more important references in a group.

This Index covers the text, the illustrations, and the Appendix. Negative references are included if they convey information of interest.

Much time and effort has been devoted to making this index as complete and useful as possible. However, in a work of this size, it is not possible to entirely avoid omissions and errors, and the lack of a reference does not necessarily mean that the desired information is not in the book. It may also be looked for under related subjects or in the Table of Contents.

In hyphenated numbers the first part indicates the chapter number, the other the page number. Following simple numbers refer to additional pages in the same chapter. For example, the entry "9-31,42, 12-6, A-4" refers to pages 31 and 42 in Chapter 9, page 6 in Chapter 12, and page 4 in the Appendix.

Index references include both text and illustrations.